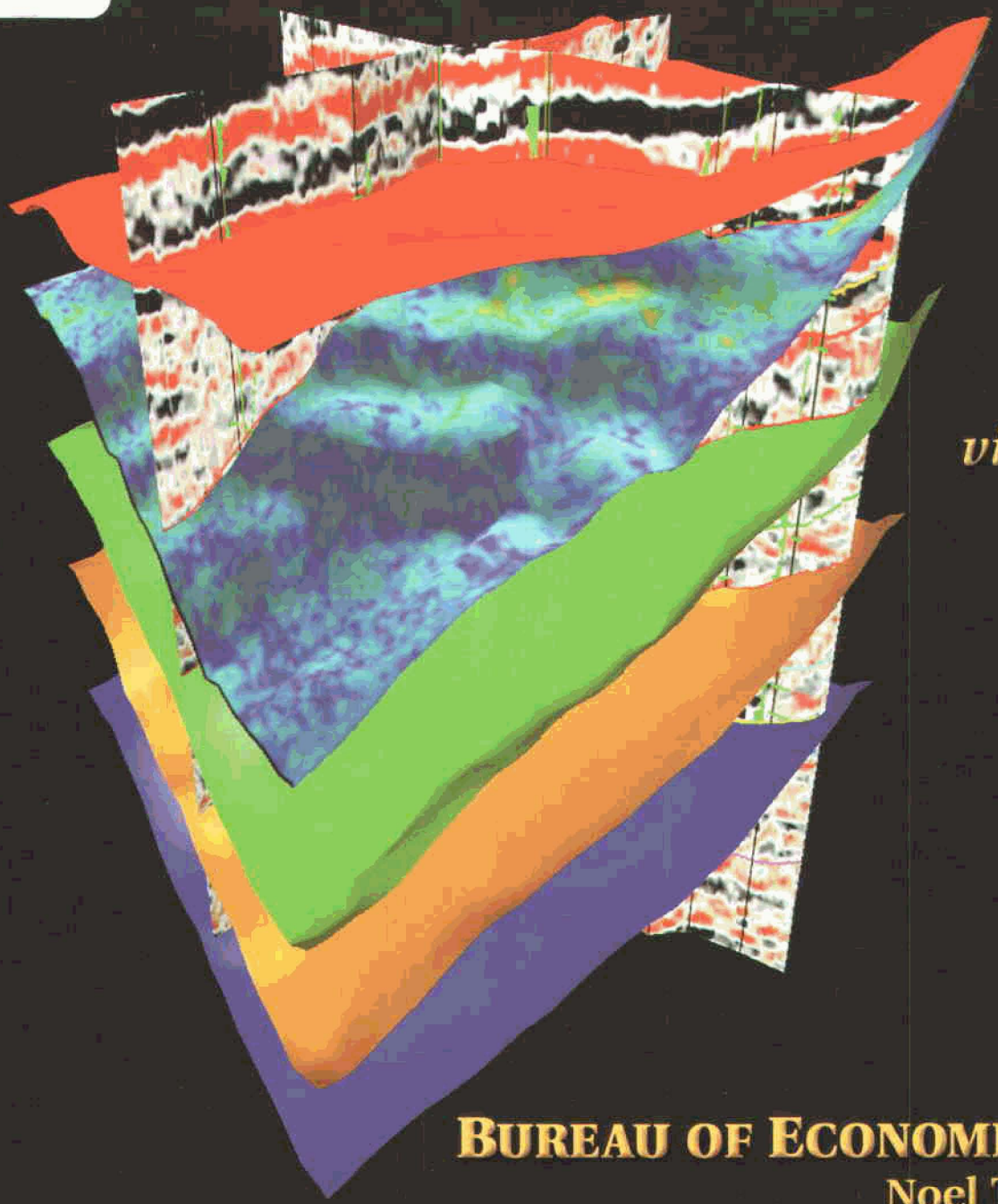
ANNUAL REPORT 1998



Reservoir visualization

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.

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Research and Administrative Office and Laboratories
J. J. Pickle Research Campus
10100 Burnet Road
Austin, Texas 78758-4497
(512) 471-1534, Switchboard
(512) 471-2145, Public Information
(512) 471-0140, Fax

(512) 471-7144, Publication Sales
1-888-839-4365, Toll-free phone (USA)
1-888-839-6277, Toll-free fax (USA)

Mailing address
The University of Texas at Austin
University Station, Box X
Austin, Texas 78713-8924
Web: http://www.utexas.edu/research/beg/

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Compilation and technical editing by Tucker F. Hentz, editing and production coordination by Nina Redmond and Lana Dieterich, word processing by Susan Lloyd, and design, layout, and cover by Jamie H. Coggin.

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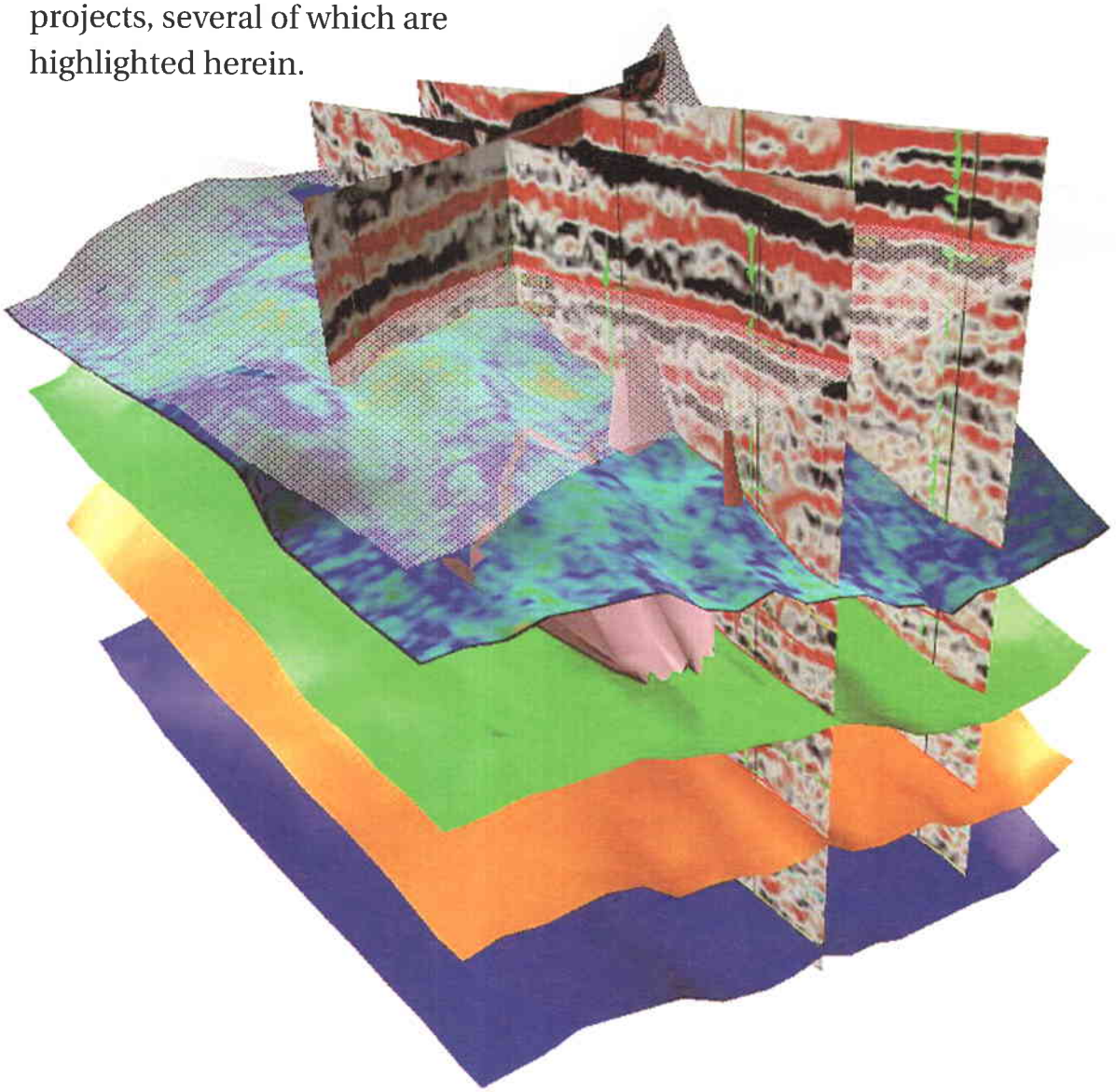
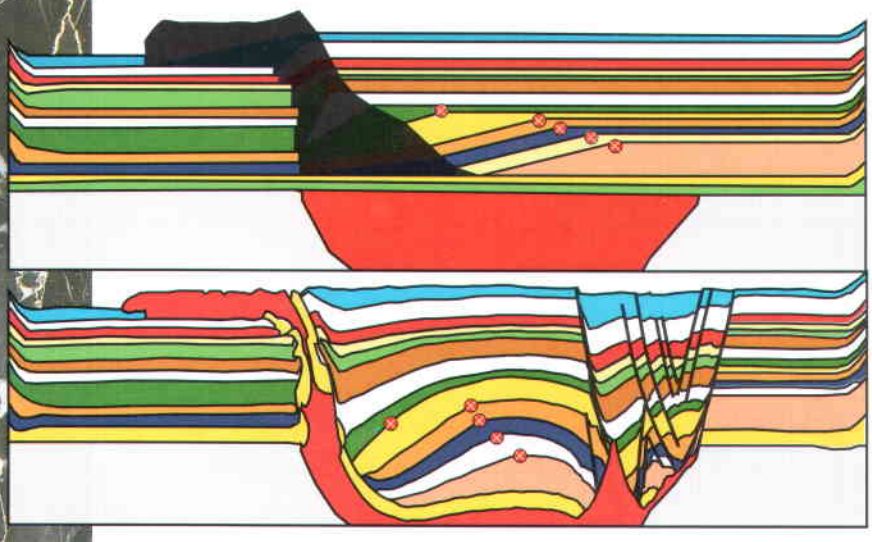
Program Support

In 1998, the Bureau of Economic Geology's operating budget was $18.0 million (in Federal equivalents) from 89 contracts and grants and line-item State appropriations. Of these projects 58 were from interagency contracts with State and local governments and from various agencies of the Federal government, and 31 contracts were with the energy industry and private institutions. In 1998, the Bureau conducted 86 research projects, several of which are highlighted herein.



Industrial Associates Energy Resource Investigations

The hallmark of Bureau energy resource investigations that are supported by industrial consortia is innovation in the development of new exploration and development strategies for the oil and gas producer. The Bureau's Clastics Reservoir Group is developing improved models of fluvial-deltaic reservoirs using data from well-exposed outcrop analogs. In 1998, the focus of the project was on two tide-influenced, fluvial-deltaic systems in the western United States. Researchers concentrated on using quantitative outcrop data as input into advanced flow models to determine the relative importance of various geologic factors such as controls on subsurface fluid-flow behavior. In a new program started in August 1998, Bureau researchers began working to explain and successfully characterize, predict, and simulate reservoir-scale structures using new scanning-electron-microscope-based imaging devices, to describe quantitatively how structures of differing scale are related, and to refine geomechanical modeling techniques. Advances in numerical modeling, physical modeling, and computer visualization by the Applied Geodynamics Laboratory last year enabled continued study of a variety of controls on salt tectonics that have direct application to subsalt exploration in the Gulf Coast Basin and other hydrocarbon-bearing salt basins of the world. The Exploration Geophysics Laboratory (EGL) focused its industry-sponsored research on developing seismic vector-wavefield technology that can improve characterization of complex reservoirs. The basic objective of the research is to create both compressional (P) and shear (S) images of reservoir systems that can be used to interpret reservoir

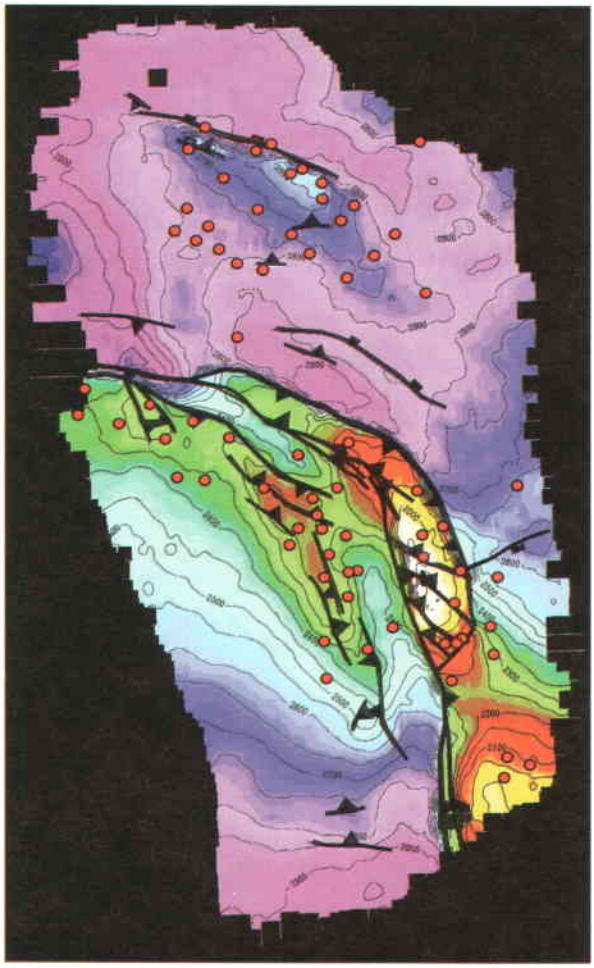


architecture, instead of just the traditional 3-D, P-wave-imaging techniques. As part of their research effort in 1998 to develop seismic vector-wavefield technology for reservoir characterization, the EGL team developed two new vector-wavefield seismic sources. These two newly tested sources will now allow S-wave seismic data to be gathered over a wide variety of terrains, including heavily timbered areas and locations where permitting restrictions exist.

Domestic Energy Resource Investigations

Bureau investigations of domestic siliciclastic and carbonate oil reservoirs continued in 1998 to stress advanced geological, geophysical, and engineering research approaches to optimizing oil-recovery strategies. These studies are funded by both State and Federal sources. In a multiyear study of deep-water turbidite sandstone reservoirs, funded by the U.S. Department of Energy (DOE), Bureau researchers have continued providing details of the reservoir architecture of two representative fields of the Delaware Mountain Group of West Texas in order to define cost-effective ways of recovering a higher percentage of original oil in place. For example, in 1998, geologic modeling of a simulated CO_2 flood in one of the fields indicated that 10 to 30 percent of remaining oil in place in the demonstration area can be produced by CO_2 injection. Also in 1998, in an outcrop-based study of the Cretaceous Ferron Sandstone of central Utah, funded by the Advanced Technology Program of the Texas Higher Educational Coordinating Board, Bureau scientists used ground-penetrating radar to interpolate the 3-D geometry and facies of sediment bodies behind outcrops of the Ferron, which is representative of a prolific class of heterolithic deltaic reservoirs in the United States.

The goal of the State of Texas Advanced Resource Recovery (STARR) project is to characterize selected reservoirs on extensive acreage owned by the State of Texas in order to aid operators in optimizing recovery of their remaining hydrocarbon resources. Resource analysis of oil and gas fields on Texas State Lands indicates that more than



3 billion barrels of oil is projected to remain at reservoir abandonment, more than half of which is mobile oil. To date, wells drilled on State Lands on the basis of STARR recommendations and with the support of allied producers are estimated to have added more than $7 million in royalty revenue to the Texas Permanent School Fund. The projected total revenue generated for the State of Texas from these additional oil and gas reserves will be more than $57 million. The University Lands Advanced Recovery Initiative is similarly examining selected University Lands reservoirs to recommend strategies for incremental recovery of the large remaining oil resource on University Lands leases. Three Permian Basin reservoirs are being studied with the support of University Lands field operators: the North McElroy Grayburg reservoir, the Pennsylvanian Unit in Block 9 field, and the Wolfcamp Unit in Block 9 field.

In a program funded by DOE to develop technology to improve operator drilling success in fracture-controlled gas reservoirs in the Appalachian Basin, 1998 seismic field tests demonstrated that one of these new vector-explosive sources developed by the Bureau's EGL generates good-quality seismic shear (S) waves, which are particularly sensitive to fractures, and that conventional seismic sources generate robust converted-mode S waves at basinwide formation interfaces lying above the major gas-producing reservoirs.

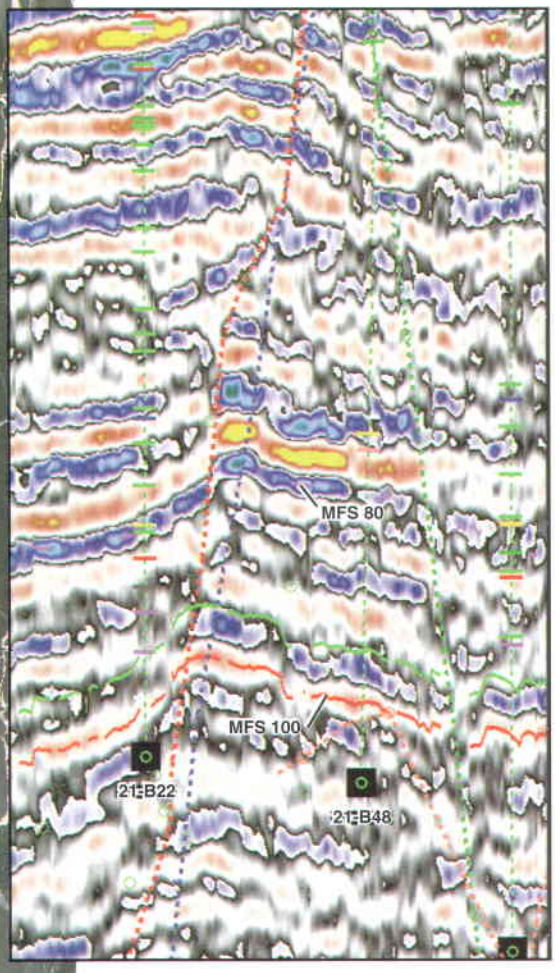
Other 1998 Bureau investigations of domestic natural-gas reservoirs emphasized strategies for basin-scale gas exploitation and realistic methods of measuring play-scale natural-gas reserve-growth potential. As part of a cooperative agreement between the Bureau and the State

of Alaska, Bureau researchers evaluated the coalbed methane resources in Alaskan coal-bearing basins by applying the basin-scale coalbed methane producibility model that the Bureau developed after a decade of research in the Rocky Mountain Foreland, western United States. The evaluation was used to test the potential of coalbed methane resources as an alternative energy source for much-needed local electrical power and home heating in rural areas of the state. Another Bureau project funded by DOE has scientists developing ways to provide 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. A major multiyear multidisciplinary reservoir-characterization study that started in late 1998, also funded by DOE, will examine, with the aid of an industry partner, several major gas fields in the Federal Outer Continental Shelf of the Gulf of Mexico basin. The overall objective of this project is to identify opportunities for infill drilling and recompletion of existing wells in these mature gas fields.

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

International Energy Resource Investigations

In 1998 the Bureau's international program involved nine reservoir-characterization and basin-analysis projects in Austria, Honduras, Saudi Arabia, and Venezuela. The Bureau is working on behalf of OMV Aktiengesellschaft of Austria to help define the remaining unrecovered oil and gas resource in Matzen field, Vienna Basin, the largest oil and gas field in Central Europe. The project completed geological work on the southern two-thirds of this 1,400-well field in late 1998, recommending multiple incremental recovery opportunities by means of recompletions and selective infill drilling. Much of the work on the project in 1998 focused on the influence of tectonics on sedimentation in the Vienna Basin. On the basis of Bureau recommendations, several potential traps related to complex structures were tested in late 1998 when existing wells were deepened. The objectives of the Bureau's study of reservoirs in Ghawar field, Saudi Arabia, funded by Aramco Service Company, are to develop a method of identifying the petrophysically significant rock fabrics, characterize their petrophysical properties, and calibrate the fabric and petrophysical properties of wireline-log response to enable accurate estimates of permeability from wireline logs. The aim is to provide a means of more efficiently identifying reservoir compartments in the prolific field.



Six Bureau investigations in Venezuela are using integrated reservoir-characterization techniques to identify and map remaining oil and develop reservoir-management strategies for more efficient recovery from several Venezuelan fields. In studies funded by Petróleos de Venezuela, S.A., Bureau researchers are examining Eocene and Miocene reservoirs in the Mioceno Norte Area,

northeast Lake Maracaibo, and Eocene reservoirs in the Maraven-VLA 6/9/21 Area, north-central Lake Maracaibo, Venezuela. Production-optimization projects are also examining lower Eocene reservoirs in the Pilar Sur Area in north-central Lake Maracaibo; naturally fractured crystalline basement, Cretaceous carbonate, and Paleocene–Eocene terrigenous-clastic reservoirs in Mara Este (Mara Liviano) field in the northwest part of the Maracaibo Basin; Tertiary and Cretaceous reservoirs and prospects in Blocks B, C, and E of South Lake Maracaibo, in collaboration with the Fundación Laboratorio de Servicios Técnicos Petroleros of La Universidad del Zulia, Maracaibo; and Oligocene and Miocene strata of the Sanvi-Guere Unit in eastern Venezuela.

Hydrogeologic and Environmental Investigations

The Bureau's hydrogeologic and environmental research expanded in 1998 by addressing international geoenvironmental characterization, as well as domestic study of toxic near-surface contaminants and subsurface waste containment. Last year was the first full year of studies by workers on the new 5-year Orinoco delta project, funded by Petróleos de Venezuela, S.A., under the direction of the Coordinación Desarrollo Armónico de Oriente. The project tasks include describing active geologic processes, geologic framework, and land cover of the fragile and nearly pristine environment of the Orinoco delta in eastern Venezuela, all part of an effort by Venezuela to encourage responsible development of this environmentally sensitive region. In a follow-up project to a previous nationwide study by the Bureau and Center for Space Research to determine the extent and rates of deforestation in Belize, a more detailed evaluation of land cover and land use in south-central Belize was conducted in 1998 to support the Government of Belize in developing current land-use maps. Funding was provided by the United Nations Development Programme through the Government of Belize, Ministry of Natural Resources. This study will provide the basis for a detailed land-cover and land-use image classification that can be applied elsewhere in Belize.

Closer to home, Bureau investigators continued to assist the Railroad Commission of Texas last year in devising cleanup solutions at nine sites in Texas where the source and subsurface extent of contamination is unknown and where complex subsurface geology will affect remediation efforts. Studies focused on cost-effective remedial solutions and investigative methods by applying nonintrusive, advanced techniques. Bureau studies to support the State of Texas in developing a site for the safe disposal of low-level radioactive waste in the Eagle Flat Region, Hudspeth County, also continued in 1998. This work is funded by the Texas Low-Level Radioactive Waste Disposal Authority and the U.S. Department of Energy. In a new 3-year, NASA-funded project, Bureau geoscientists will examine whether NASA's airborne synthetic aperture radar (AIRSAR) can be used to screen watersheds rapidly for salinization hot spots, allowing higher resolution, airborne and ground-based electromagnetic induction surveys to focus on areas where problems are likely to exist.

One possible method of reducing the world's atmospheric carbon budget is to sequester carbon dioxide (CO_2) in aquifers and hydrocarbon reservoirs. In two new 1998 projects, the Bureau began investigating the geologic feasibility of such a process. Bureau scientists, funded by the Electric Power Research Institute, are examining the suitability of Texas oil and gas reservoirs for sequestering CO_2 produced by major power plants. Saline aquifers have, moreover, been widely recognized as having high potential for long-term sequestration of greenhouse gases. In another project that uses reservoir-characterization and geologic-play approaches, Bureau researchers are determining what hydrogeologic settings are best for CO_2 injection.

Coastal Investigations

Fourteen projects composed the Bureau's coastal investigations program in 1998, which stressed historical trends in coastal-shoreline change, wetland creation and preservation, and coastal processes and their influence on coastal management. Because San José Island is one of the few barrier islands on the Texas coast that has not been significantly altered by human activities, it serves as a good test area for Bureau researchers to study the physical processes that cause shoreline movement. The objectives of the study were to map the Gulf shoreline on the island using Global Positioning System (GPS) techniques and to evaluate shoreline movement since 1974. In addition, previously mapped shoreline positions (1860's to 1974) were digitized by means of a Geographic Information System (GIS) so that future comparisons of shoreline position and calculations of rates of change can be automated and precise. Residents of the Alamo Beach–Magnolia Beach–Indianola Area of Calhoun County have witnessed long-term gradual bluff and beach retreat along most segments of the west shore of Matagorda and Lavaca Bays. In a study sponsored by the Golden Crescent Regional Planning Commission with funding from the Texas GLO Coastal Management Program and Calhoun County, Bureau coastal specialists began analyzing the geological setting and physical processes that control beach erosion near Magnolia Beach to recommend erosion-mitigation options that are cost effective and that have negligible environmental impacts. Scientists from the Bureau and The University of Texas at Austin, Department of Geological Sciences, are also working with students

from Ball High School at Galveston, Texas, in a coastal research project funded by the Texas Coastal Management Program, Conoco, and the Exxon Foundation. Researchers are training teachers and students in the Marine Science class to monitor dune and beach changes on Galveston Island.

In an investigation funded by the Texas General Land Office (GLO) and the U.S. Environmental Protection Agency (EPA), the Bureau has become active in inventorying and evaluating marsh restoration and creation projects in the Galveston–Trinity Bay System. Similarly the Bureau is the lead agency in a cooperative study funded by the EPA and the Texas Natural Resource Conservation Commission, along with the Texas Parks and Wildlife Department and Texas A&M University at Corpus Christi, to determine the status and trends of changes in the wetlands, shorelines, and vegetation cover on islands in Corpus Christi and Aransas Bays. These types of data are critical for developing sound and comprehensive management practices in this nationally recognized estuarine system.

Funded by the National Aeronautics and Space Administration and jointly conducted by the Bureau and the Center for Space Research at The University of Texas at Austin, AIRSAR mapping of coastal topography, sedimentary environments, and wetland vegetation is being developed by Bureau researchers. Because the shapes, elevations, and distributions of sediment and vegetation of barrier islands can change dramatically over a short period of time (such as during a storm), the precise mapping made possible by means of AIRSAR is essential for effective coastal management.

Bureau Establishes Virtual Environment Center—"EarthView Texas"

The EarthView Texas Virtual Environment Center offers significant new opportunities to explore the world around us. By allowing scientists and students to view and interact with information in completely new ways, this leading-edge visualization technology will greatly expand the Bureau's ability to provide information on natural systems and resources.

Viewing in stereo is important in perceiving depth, and it is part of the virtual reality (VR) experience. VR provides observers with a field of vision that extends to as much as 180°, closely matching our daily experience. VR allows full immersion in models and data, unlike any other technology, and it allows scientists to inspect data at multiple scales simultaneously and view multiple data sets within a single area of interest. Multidisciplinary collaborative teams can also interpret data from the same viewpoint with VR, permitting rapid understanding of complex relationships.

During 1998, the Bureau developed four models for visualization in a VR environment: the Edwards aquifer, geology of the Austin West Quadrangle, airborne-laser altimetry of Galveston Island, and a proprietary seismic-data volume. Multiple "proof of concept" demonstrations were provided for a wide cross section of Bureau clients. These demonstrations produced enthusiastic commentary from any who experienced this new way of looking at geoscience. Acquisition of the necessary equipment, software, and model-building skills is under way so that a permanent Virtual Environment Center at the Bureau can be realized.

Seismic Vector-Wavefield Research Program Acquires World-Class Geophysical Test Site

Working through a consortium of 32 companies, the Exploration Geophysics Laboratory (EGL) at the Bureau has implemented a research program to develop all aspects of 3-D seismic vector-wavefield technology. The intent of this program is to establish the principles by which compressional (P) and shear (S) seismic data can be used to better characterize reservoir systems.

As a result of this broad base of industry support, particularly significant contributions being provided by Visos Exploration and by Petroleum GeoServices, the Bureau has a joint ownership of

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Immediate area around the three cased wells (Nos. 2, 4, and 9) at the Devine Test Site in Medina County, Texas, which was donated in 1998 by BP to The University of Texas at Austin for the Bureau's use. Photo by Bob A. Hardage.

approximately 50 mi^2 of 3-D vector-wavefield data over a variety of reservoir systems. These data compose one of the largest seismic vector-wavefield data bases ever collected by industry and offer immense research opportunities for Bureau scientists. Particular research interests include developing techniques that streamline multicomponent data acquisition, improving data-processing procedures used to create S-wave images, and establishing the principles of vector-wavefield seismic stratigraphy.

An invaluable asset that has been added to this seismic vector-wavefield research program is the world-class geophysical test site developed by British Petroleum (BP). In the fall of 1998, BP donated its 100-acre seismic field laboratory in Medina County, Texas, to The University of Texas at Austin for use by the Bureau of Economic Geology. This test facility, popularly known as the Devine Test Site, has (1) three cased wells (each 3,000 ft deep) that were constructed specifically for downhole seismic experimentation, (2) cement and gravel pads for vibrator-source testing, and (3) shallow cased holes 100 and 200 ft deep for deploying nondestructive borehole seismic energy sources. A large number of experimental well log data, crosswell seismic data, and vertical seismic profiles recorded at the test site were included in the donation.

The test site will be an immediate and critical resource utilized by the EGL's Seismic Vector-Wavefield Research Consortium and will be invaluable in expanding the Bureau's seismic research program. Other university, government, and industry developers of seismic and geophysics technologies can use the test facilities and the historical data base by contacting Donna Cole at the Bureau of Economic Geology (phone: 512-471-0369; fax: 512-232-2388; E-mail: coled@begv.beg.utexas.edu). Detailed information about the test site can be obtained by reviewing the Bureau's Web site at http://www.utexas.edu/research/beg/.

Bob Hardage Honored by the Society of Exploration Geophysicists

Bob Hardage, principal scientist at the Bureau's Exploration Geophysics Laboratory, is the recipient of the 1998 Special Commendation Award from the Society of Exploration Geophysicists (SEG). He received the award, which is one of the highest honors bestowed annually to SEG members, at the society's 1998 annual meeting in New Orleans. 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."

Bureau Collaborative Project Enhances Data Availability in the Texas–Mexico Border Area

The Texas Higher Education Coordinating Board awarded a large research grant to the Bureau and cooperating universities in the Texas–Mexico border area to develop new "seamless" data sets that span the Rio Grande. The collaborating schools are The University of Texas at Brownsville, The University of Texas Pan American at Edinburg, The University of Texas at El Paso, and Texas A&M International University at Laredo. Each of the border schools is digitizing geologic data from adjacent areas of Mexico, and the Bureau is preparing companion geologic data sets on the contiguous Texas side of the border. A large number of students are participating in this study. Training in digital mapping and analysis of data in a geographic information system (GIS) are important facets of this project, and opportunities for training and participation in workshops are being provided to students and staff.

The Bureau is responsible for project coordination and for melding the Mexican and Texas data into a seamless geologic base, which is needed by planners, developers, policy makers, scientists, and others who are attempting to address a variety of issues in this important region of the state. The final year of the project will see an analysis of map accuracy and development of related data sets that will address issues of specific concern in various segments of the border. In particular, natural resources, surface- and ground-water hydrology, land use, and other environmental topics will be studied. The results of these studies will be made widely available to those working in the border area. These data and the skills developed by those students who will have worked on this project will benefit the environment and the economy of the Texas–Mexico border area both now and into the next century.

Bureau Establishes New Industrial Associates Program to Study Fractured Reservoirs

The Fracture Research and Application Consortium (FRAC), an industrial associates program for research on fractured and faulted reservoirs that was founded in August 1998, hosted a workshop in Austin that was attended by representatives of 10 companies. The focus of the program is to explain and successfully characterize, predict, and simulate fractured reservoirs. The FRAC consortium has already made important advances in characterization and simulation methods, including creation of a practical method for assessing the capability of natural fractures to transmit fluid. The next phase of the project will include research on fractured carbonate reservoirs.

Bureau Scientists Reach Out to Public Schools

For many years the Bureau has viewed public service as one of our major responsibilities. Providing better information on the geology, natural resources, and environment of Texas to school teachers, students, and the general public is an important part of this public outreach. Some of this service occurs through formal Bureau functions, such as the activities of the Public Information Geologist, who answers thousands of inquiries from the public each year or sales by our Publication Sales office, which is our outlet for printed materials. Often unrecognized, however, are the many hours that Bureau staff volunteer to provide lectures, field trips, and tours, and to answer questions, develop new materials for the classroom, or attend teacher workshops and conventions. Recently, staff members have also become involved in a program that allows high-school students to work with us on research projects at the Bureau, and we have established a program that involves high-school students and teachers in a shoreline-monitoring program on the Texas coast. As a result of staff participation in the Texas Environmental Awareness Network, which provides an opportunity for Texas agencies to collaborate on environmental education activities, Bureau scientists and their research have appeared in 1998 on the popular educational television series, *Eye on Earth*.

Key to our public service is our new "Down to Earth" series that began with the publication on McKinney Falls State Park. This year we began to explore the world of virtual reality and the power of this research tool in education and hope to make this exciting visualization technology more available to students through the new "EarthView Texas."

In September the Bureau hosted 80 students from New

Braunfels High School's math and chemistry classes. Math teacher Bonnie Leitch and chemistry teacher Cathleen Rhodes organized their curricula around the topic of the Edwards aquifer this past year, with support from a grant from GTE. The Bureau contributed to the teachers' project in a series of lectures. Drawing on samples from our Core Research Center, Bureau scientist Susan D. Hovorka showed examples of rocks that make up the Edwards aquifer and discussed how aquifer porosity developed. Robert E. Mace showed how math is used to describe the hydrogeology of the Edwards aquifer. Alan R. Dutton used his lecture on aquifer chemistry to illustrate the use of logarithms, solution of equations, and graphical presentation of data.

Bureau Sponsors Discussions on Ground-Water Resources of Texas and Central Mexico

The Bureau was delighted to host two visits from Mexico by delegations of Federal and State personnel and private citizens involved in addressing the important issues concerning ground-water resources. In August the Bureau hosted a delegation of 14 representatives from the Comisión Nacional del Agua, Querétaro Comisión Estatal de Aguas, and the Querétaro Consejo Tecnico del Aguas Subterraneas (COTAS), an association of ground-water users and managers. The visit focused on Texas water law and ground-water management techniques. As part of the visit, the Bureau arranged field trips and technical discussions with personnel from the Mesa Underground Water Conservation District, Texas Water Development Board, Edwards Aquifer Authority, and Barton Springs/Edwards Aquifer Conservation District.

In December, another delegation of 30 representatives from the Comisión Estatal de Agua y Saneamiento de Guanajuato (CEASG); the Guanajuato COTAS for Celaya, Irapuato-Valle de Santiago, Laguna Seca, Pénjamo–Abasolo, Salvatierra–La Cuevita, and Silao–Romita; and the Universidad Iberoamericana in Leon, Guanajuato, visited the Bureau for discussions on public education in ground-water issues and the role of ground-water modeling in aquifer management. The December delegation was welcomed to the Bureau by Noel Tyler, Director, and Sr. Francisco Roux Lopez, General Consul of Mexico. At present, ground-water reserves in Querétaro and Guanajuato are being depleted. These government agencies and users groups are looking for ways to adopt successful ground-water management policies to help solve the water shortage problem in Central Mexico.

Bureau hydrogeologist Robert Mace (right) shows core at the CRC to members of CEASG and COTAS from Guanajuato, Mexico. Photo by David M. Stephens.

Railroad Commissioner Given Firsthand View of Bureau Project Area

In May Charles R. Matthews, Chairman of the Railroad Commission of Texas, was escorted by Bureau researchers Jerry Lucia, Shirley Dutton, Andrew Scott, and Alan Dutton on a field trip to outcrop analogs of West Texas oil reservoirs. Jerry Lucia and Shirley Dutton explained the basic geology of major classes of Permian Basin oil fields and described the role of outcrop studies in explaining production performance from reservoirs in the Permian Basin. The trip began with an airplane overflight of the Guadalupe Mountains for viewing regional facies relationships exposed in this world-class outcrop. The group visited San Andres reservoir analogs at Lawyer Canyon and Last Chance Canyon, where Bureau geologists and engineers have conducted extensive reservoir studies. Cherry and Brushy Canyon sandstones, which are important oil reservoirs in the Delaware Basin, were viewed in excellent exposures in roadcuts at Guadalupe Pass. Chairman Matthews noted that the Permian Basin supplies more than 60 percent of the oil produced in Texas and about 15 percent of U.S. domestic production.

Chairman Charles R. Matthews (seated), and Bureau scientists Alan R. Dutton, F. Jerry Lucia, Shirley P. Dutton, and Andrew R. Scott pause after viewing San Andres outcrops at Lawyer Canyon along the Algerita Escarpment in New Mexico. Photo by Alan R. Dutton.

Staff Promotions

In 1998, the following members of the Bureau staff received promotions: **Patricia A. Alfano** to Computer Illustrator Technician, **William C. Bergquist** to Computer Illustrator, **Jamie H. Coggin** to Graphics Designer, **Christian T. Conly** to Computer Illustrator Technician, **Nancy A. Cottington** to Computer Illustrator, **Dixon E. Coulbourn** to Computer System Development Specialist, **Susan N. Krepps** to Technical Illustrator I, **Joel L. Lardon** to Manager of Graphics Services, **F. Leo Lynch III** to Research Associate, **Richard P. Major** to Senior Research Scientist, **Amanda R. Masterson** to Administrative Associate, **Kerza A. Prewitt** to Senior Computer Illustrator, **Kristina A. Redmond** to Editor I, **Enrique Romo** to Administrative Assistant, and **Debra A. Stacy** to Administrative Associate.

New Research Staff

Andres Aslan joined the Bureau as a Research Associate working on the Orinoco Delta project. Andres received a B.S. in Geology from Brown University and an M.S. and Ph.D. in Geological Sciences from the University of Colorado at Boulder, where he studied sea-level influences on Holocene Mississippi River flood-plain evolution in Louisiana. His research interests and experience are in fluvial sedimentology, geomorphology, and alluvial stratigraphy, including study of paleosols. He has worked on modern and ancient alluvial deposits in the Rocky Mountain region, the Gulf Coast of Louisiana and Texas, and northwest Pakistan, and he taught previously at Mary Washington College and Oberlin College.

Yaguang Gu, a Research Scientist Associate, is working on several of the Bureau's international projects. He received his M.S. in Petroleum Engineering from The University of Texas at Austin. Before obtaining his Master's degree, Yaguang worked for 8 years as a petroleum engineer for China National Petroleum Corporation.

Gregory J. Jeffers, a Research Scientist Associate, joined the Bureau as a GIS analyst. Greg has a B.S. in GIS/Cartography from Southwest Texas State University. Before joining the Bureau, he worked as a GIS Technician for Rust Environment and Infrastructure, where he spent 2 years creating a Digital Nautical Chart data base for the National Imagery and Mapping Agency. **David A. Kratz** is working in Information Technology Services as a Senior Network Analyst. Before joining the Bureau, David worked on the Ocean Drilling Program (ODP) at Texas A&M University as a Microcomputer Specialist. At ODP, he worked primarily with Microsoft NT systems and network services. He has a B.S. in Political Science from Texas A&M University and an AAS in Network Administration from Blinn College. **Malcolm P. R. Light** returned to the Bureau as a Research Scientist after an 11-year absence to begin reservoir-characterization work in Mara Este field in Venezuela, a field where structure exerts a major control on hydrocarbon distribution. During his absence, Malcolm worked extensively in hydrocarbon exploration in the Far East, southern and western Africa, the South Atlantic, South America, and the North Sea.

Janaka B. Paulis, a Research Scientist Associate, joined the Bureau to work with the reservoir engineering group. Janaka has an M.S. in physical organic chemistry from The University of Texas at Austin, where he is currently working toward his Ph.D. in petroleum engineering.

Scott D. Rodgers joined the Bureau as Manager of Multimedia Systems. A graduate of The University of Texas at Austin with a B.S. in Radio-Television-Film, Scott has developed commercial applications of active and interactive media for industry and technology. His primary focus will be developing the Bureau's virtual reality system, the Internet, and digital media publications.

Martha L. Romero originally joined the Bureau as a Graduate Research Assistant and has been hired as a Research Scientist Associate. A native Colombian, Martha is working in the Bureau's petrophysical group as data manager for projects funded by Petróleos de

Venezuela, S.A. **Ronald L. Russell** joined the Bureau as a Research Scientist Associate and is working on the Matzen field project. Ron is responsible for maintaining the ACCESS data base, updating the OPENWORKS data base, and digitizing maps. He spent the last 31 years in the military as an operational technician for a mainframe computer system, an officer accountable for as much as $1.3 billion of military equipment, a government housing manager, a property book officer for a nuclear weapon unit, and various other assignments. Ron received a B.S. in Business Management from the University of Maryland and an M.A. in Economics from the University of Oklahoma. **Jianxin (Steve) Shi** is a Research Associate working on the University Lands project. He received his Ph.D. in Petroleum Engineering from The University of Texas at Austin. Before joining the Bureau, he worked at ARCO as a research reservoir engineer. His research interests are in reservoir modeling and simulation, miscible flooding, and petrophysics. **Andrew G. Warne** joined the Bureau as a Research Associate to work on the Orinoco Delta project. Prior to joining the Bureau, Andrew worked at the U.S. Corps of Engineers Waterways Experiment Station and Smithsonian Institution on numerous geoenvironmental issues. He has a Ph.D. from the University of North Carolina.

Frank Brown Returns to the Bureau after 9 Years of International Consulting

L. Frank Brown, Jr., returned to the Bureau midyear as a Senior Research Fellow. He retired from the Bureau in 1989 and except for 6 years at Baylor (1960–66), he had been at UT for 27 years beginning in 1957. Frank is Emeritus Professor in The University of Texas at Austin, Department of Geological Sciences (1971–present), and he served as an Associate Director at the Bureau (1970–84). He did international consulting and training part-time in about 35 countries from 1970–89, and full-time from 1989–1998. Frank was an American Association of Petroleum Geologists (AAPG) domestic (1972) and international distinguished lecturer (1994), a Petroleum Exploration Society of Australia international lecturer (1985), and an AAPG continuing education instructor (1970–96). Frank was also a recipient of an AAPG Certificate of Merit (1980) and the Cheney Science Award from the AAPG Southwest Section (1987). In addition to research supervision at the Bureau, he conducted depositional systems and sequence stratigraphic studies of Upper Pennsylvanian and Lower Permian rocks on the Eastern Shelf of the Permian Basin, contributed mapping on five 1:250,000-scale *Geologic Atlas of Texas* sheets, and directed and coauthored the seven folios of the *Environmental Geologic Atlas of the Texas Coastal Zone*. He is currently involved in several petroleum-related sequence stratigraphic studies at the Bureau.

Awards and Honors

Bob A. Hardage is the recipient of the 1998 Special Commendation Award from the Society of Exploration Geophysicists. He received the award at the society's 1998 annual meeting (see feature article on the award earlier in this "Highlights" section). **Roger Tyler** won Second Place, Best Poster Award, from the Gulf Coast Association of Geological Societies (GCAGS) for his paper, "Project STARR—State of Texas Advanced Oil and Gas Resource and Recovery Program," presented at the 1997 GCAGS Annual Meeting. This paper was coauthored by **R. P. Major, Mark H. Holtz, H. Scott Hamlin,** and **Mark R. Vining.**

The bureau poster "Airborne Laser Swath Mapping of Galveston Island and Bolivar Peninsula" by **Roberto Gutierrez, James C. Gibeaut, Matthew P. Mahoney**, Melba M. Crawford, and Solar Smith was named Best of Session by the judges at the Fifth International Conference for Remote Sensing for Marine and Coastal Environments in San Diego.

The poster that **Tucker F. Hentz** co-authored with B. J. Bascle, L. D. Nixon, R. H. Peterson, and C. J. John, and presented at the 1998 GCAGS Meeting in Corpus Christi, "Newly Defined Plio-Pleistocene Plays, North Gulf of Mexico: Field Characteristics and Production Statistics," has been awarded First Place for Best Poster.

Recipients of the 1998 UT Service Awards (sitting left to right): Kerza Prewitt (15 years), James A. Doss, Jr. (15 years), Susan Lloyd (10 years), and (standing left to right) William A. White (25 years), Edward W. Collins (20 years), and Tucker F. Hentz (15 years). Photo by David M. Stephens.

Two Senior Bureau Researchers Retire

Robert A. Morton, an internationally recognized coastal scientist, retired from the Bureau in August after 26 years of service in order to accept a senior position with the U.S. Geological Survey in St. Petersburg, Florida. Bob arrived at the Bureau in 1972 during a period of rapid institutional expansion, beginning his career with the South Texas Environmental Geology Project. He has made an indelible mark on the Earth science profession through his untiring work on such significant projects as Texas historical shoreline monitoring; the Submerged Lands atlases; geopressured–geothermal energy; Miocene, Pliocene, and Pleistocene structure and stratigraphy of the Texas coastal plain and continental shelf; and general studies of the modern depositional environments of the Texas coast. The magnitude of his accomplishments is reflected in a list of his publications: he is the first author of 21 Bureau publications, 4 books, 46 articles, 28 abstracts, and 2 book chapters. Excluding contract

reports, he is listed as an author on 177 publications. He also has numerous committee responsibilities at the Federal, State, and professional organization level. At the Bureau, he directed or co-directed 63 research projects funded at more than $10 million dollars.

Although Bob spent most of his professional life at the Bureau, he worked for Chevron as a petroleum geologist from 1966 through 1969, between receiving his Master's degree in 1966 and his Ph.D. in 1972 at West Virginia University. At the Bureau, he served as a Research Scientist Associate from 1972 through 1976, a Research Scientist from 1976 through 1987, an Associate Director from 1980 through 1984, and a Senior Research Scientist from 1987 through the time of his retirement. His colleagues always described him as a tireless and dedicated worker; his prodigious accomplishments while at the Bureau will be remembered and appreciated for many years to come.

E. G. (Jerry) Wermund, Jr., started his long and productive career at the Bureau in October 1973 and served in a number of prominent research and administrative capacities. His legacy is one of uncompromising quality of research and untiring devotion to Bureau administration and to the various scientific committees and professional organizations with which he was associated. From 1973 through 1978 he was principal scientist of an environmental study for the Texas Water Development Board of the Nueces, San Antonio, and Guadalupe River basins. In 1974, he was appointed Associate Director at the Bureau, a key position he held until 1988. Jerry was manager and principal liaison officer for the U.S. Department of Energy (DOE) high-level waste-isolation projects that examined the salt domes of East Texas and the Palo Duro Basins. As liaison officer, he effectively represented the Bureau when dealing with the Office of the Governor, State legislators, county governments, Battelle Research Institute, and the DOE.

Jerry served Texas as Co-Chair on the Regional Technical Working Group for Outer Continental Shelf leasing by the Minerals Management Service, Gulf Coast office, from 1976 through 1994. He also represented the Bureau on the interagency task force of the Texas Natural Resources Information System and served on the Texas Mapping Advisory Committee. Jerry participated in initiating the successful U.S. Environmental Protection Agency National Estuary programs in Texas and represented the Bureau on scientific/advisory committees for Galveston Bay (1991–1996) and Corpus Christi Bay (1996–1998).

While at the Bureau, Jerry was active in several professional societies. He served on publications and membership committees of the Geological Society of America and the environmental and publications committees of the American Association of Petroleum Geologists. He is past president of the Austin Geological Society and the Gulf Coast Association of Geological Societies and served as general chairman for the latter in its first Austin meeting in 1977.

In retirement, Jerry plans to write books for children, hoping to create an early knowledge of geology and Earth sciences.

In Memoriam

Virgil E. Barnes
1903–1998

The Bureau lost a remarkable man in 1998. Virgil E. Barnes, a scientist at the Bureau since 1935, died on January 28.

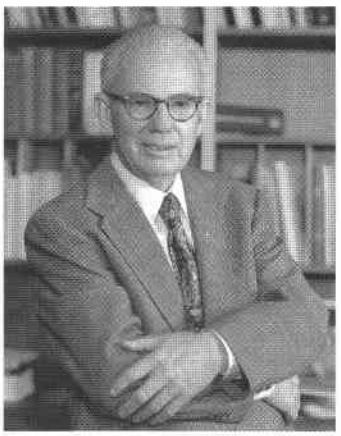
Dr. Barnes's professional achievements were outstanding, his publishing record spanning the years 1927 to 1995. During this period, he published more than 250 books, papers, maps, articles, and abstracts. Dr. Barnes also received numerous awards, including Distinguished Texas Scientist for 1988 by the Texas Academy of Science; the Barringer Award, Meteoritical Society, in 1989; and the Public Service Award of the American Association of Petroleum Geologists in 1993.

Virgil Everett Barnes was born in Chehalis, Washington, on June 11, 1903. He completed his Bachelor's and Master's degrees at Washington State College (now University) in 1925 and 1927, respectively. His Ph.D. was earned at the University of Wisconsin in Madison in 1930. He then spent a year of postdoctoral study in Texas and met Mildred (Milla) Adlof in Austin during the spring of 1931. He and Milla were married on September 28, 1932.

After a year of unemployment following the Great Depression, Dr. Barnes worked for the U.S. Geological Survey (USGS). During this period, Dr. Barnes was diagnosed with a condition affecting his spine and rib cage that led doctors to believe he probably would not live to see his children reach adulthood.

The couple decided to begin a family anyway, and soon after they learned that they were expecting, Dr. Barnes was put on furlough by the USGS. His search for work brought him to Austin, where he was hired by the Bureau of Economic Geology to put the well-sample collection in order.

During Dr. Barnes's career at the Bureau, he began and finished the *Geologic Atlas of Texas*, a 29-year project mapping the entire state at a scale of 1:250,000. He also made two tektite research trips around the world, 1960–61 and 1964–65, accompanied by Mrs. Barnes, who acted as organizer and colleague. As a result of their travels, Virgil Barnes became a worldwide expert on tektites. His wife assisted him on all his publications, and eventually they coauthored a definitive book on tektites.



Dr. Barnes's health problems would have stopped most people from conducting field work, but if anything they seemed to spur him on to bigger things. Even the high altitudes of the Andes did not keep him from doing research. He also had arthritis, starting in his teenage years, but he never let it slow him down.

Dr. Barnes was still coming to the Bureau daily right up to the time he was hospitalized with his final illness.

Virgil and Milla Barnes had one son, Virgil II, and two daughters, Louise and Elizabeth. All three went on to earn Ph.D.'s and establish successful careers. Milla Barnes died in 1994. The couple are survived by their children and six grandchildren.

— by Patricia Downs

Research

Energy Resource Investigations

Industrial Associates Programs

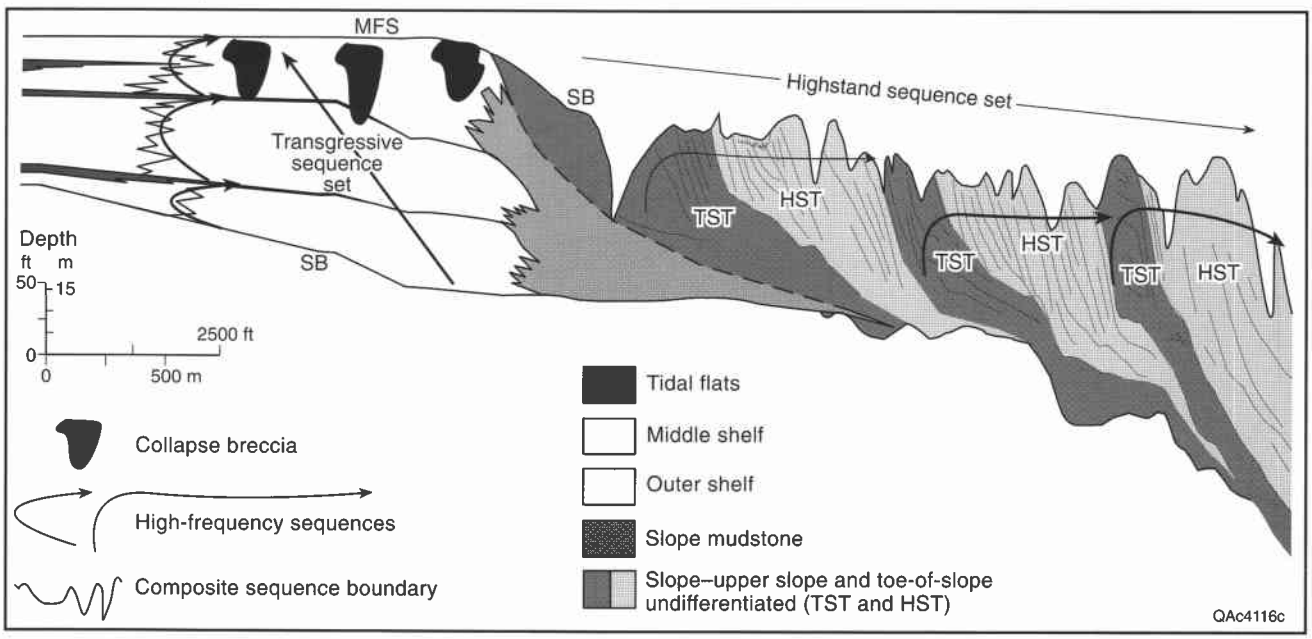
Reservoir Characterization Research Laboratory: Characterization of Carbonate Reservoirs

F. Jerry Lucia and Charles Kerans, principal investigators; Stephen C. Ruppel and James W. Jennings, Jr.; assisted by Fatma Akyurek, Eduardo E. Ariza, Rashidul Hassan, and Kirt A. Kempter

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; Amoco; Anadarko; Aramco Services Company; ARCO Exploration and Production Technology; BP International Limited; Elf Aquitaine; Exxon Production Research Company; Japan National Oil Corporation; Marathon Oil Company; Mobil New Business Development; Pan Canadian; Pennzoil Exploration and Production Company; Phillips Petroleum Company; Petroleum Development Oman LLC; Texaco Inc.; TOTAL; and UNOCAL, Inc. In addition, the program is supported by GeoQuest, 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 of developing methods of 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 of characterizing the



Outcrop-analog model of coastal paleokarst, Lower Permian, Apache Canyon, Sierra Diablo Range, West Texas. Knowledge of distribution of karst features relative to high-resolution sequence framework helps researchers in subsurface prediction of paleokarst development. SB=composite sequence boundary, MFS=maximum flooding surface, TST=transgressive systems tract, HST=highstand systems tract.

geologic architecture and the distribution of petrophysical properties in carbonate-ramp reservoirs. Studies of Permian rocks are currently being focused on Grayburg, San Andres, and Clear Fork reservoirs of the Permian Basin, West Texas, particularly the Clear Fork and Abo reservoirs. A world-class outcrop of the Clear Fork Group and the Abo occurs in the Sierra Diablo Mountains, West Texas. Detailed chronostratigraphic, rock-fabric, and petrophysical studies are being conducted at this outcrop to better explain the facies and petrophysical architecture of Clear Fork reservoirs. Outcrop studies of the Abo have concentrated on characterizing the effects of solution karsting on reservoir development. Abo karsting includes cavern formation and collapse; collapse and fracturing continue upsection into the overlying lower Clear Fork strata. Studies of Cretaceous strata have focused on the large Cretaceous reservoirs in the Middle East. Outcrop analogs to the Middle East reservoirs are found in the world-class outcrops located in 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. This information has been applied to two Middle Eastern Cretaceous reservoirs.

Subsurface studies are currently focused on South Wasson Clear Fork field operated by Altura; Kingdom Abo field, which has Pennzoil, Altura, and Exxon interests; and a Middle East Cretaceous reservoir operated by Petroleum Development Oman. A new petrophysical model has been developed for Clear Fork reservoirs and incorporated with the sequence stratigraphic framework to illustrate the rock-fabric approach to modeling Clear Fork reservoirs. Descriptions of core material from Kingdom Abo field reveal karsting effects similar to those present in the outcrop study area. Analysis of the 3-D seismic survey from this field can be interpreted to display the 3-D karst pattern.

Petrophysical and reservoir studies include (1) the development of a new method for estimating permeability within the oil column by using water saturation and porosity log calculations, (2) new analyses of our extensive collection of outcrop petrophysical data and their implications for fluid-flow modeling, and (3) fluid-flow scaleup for short-range carbonate heterogeneities. These research results are based on our extensive subsurface and outcrop studies and are directed at our goal of improving petrophysical characterization of carbonate reservoirs.

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

Shirley P. Dutton, Christopher D. White, and Brian J. Willis, principal investigators; Lesli J. Wood; assisted by Luciano L. Correa, Sharon L. Gabel, Mulugeta Feseha, Yugong Gao, and Keshav Narayanan

Integrated geologic and engineering studies carried out by the Clastic Reservoirs Group (CRG) are developing improved models of fluvial-deltaic reservoirs by using data from well-exposed outcrop analogs. Globally reservoirs in fluvial-deltaic rocks are an important resource, but these reservoirs are a challenge to develop because of interwell-scale heterogeneity. Improved reservoir models are needed to quantify internal reservoir architecture and characteristic facies dimensions and to predict accurately the spatial variation of petrophysical properties. Although it is difficult to determine the spatial distribution of interwell-scale reservoir properties in the subsurface, outcrop data can provide a continuous image of fine-scale facies architecture. The objectives of this project are to (1) develop the capability of predicting facies architecture and permeability structure at the interwell scale in a spectrum of fluvial-deltaic reservoirs; (2) integrate quantitative geologic data into realistic, geologically constrained, reservoir models; and (3) incorporate this geological framework into reservoir engineering and simulation models to upgrade detailed data, study sensitivities, and optimize field-development strategies. A sequence stratigraphic framework of the outcrops is established to provide a context that allows the application of results to analogous reservoir systems worldwide.

The focus of the project this year was on tide-influenced fluvial-deltaic systems because ancient outcrop examples of tide-influenced deltas have rarely been documented and there are few field-scale studies of outcrop analogs. The two tidal systems being investigated are the Frewens Sandstone of the Frontier Formation in central Wyoming and the Sego Sandstone in eastern Utah. The Frewens Sandstone is a superbly exposed, tide-influenced, lowstand delta system that prograded into an embayment between more wave dominated delta lobes. Geologic data collection in the Frewens was completed previously, and work this year concentrated on using the quantitative outcrop data as input into flow models to determine the relative importance of bedding, facies, shales, and diagenetic cements

as controls on subsurface fluid-flow behavior. Shale length and continuity are of particular interest to subsurface reservoir characterization because shales can baffle or isolate parts of a reservoir. Detailed shale maps collected in the Frewens Sandstone were used to develop methods for estimating the true distribution of shale lengths by correcting for the effects of shale truncation in limited outcrop exposures.

The Sego Sandstone is a tidally influenced, lowstand, fluvial-deltaic system characterized by abrupt shifts in shoreline position that juxtaposed offshore deposits and coarser grained tidal bars. Heterogeneities reflect complex patterns of deposition within tidal systems and stratigraphic cycles of shoreline progradation, valley incision, and estuarine filling. Field-data collection this year focused on (1) detailed study of an area of valley incision and (2) collection of regional outcrop data for developing a sequence stratigraphic framework of the Sego. The regional stratigraphic work included assembling a subsurface data base from well logs that tie directly into the outcrops and a core sample taken 1 mi behind the outcrop. The study of the Sego is designed to compare and contrast this system with that of the Frewens sandstones, which differs in stratal architecture, facies patterns, and shale distribution.

This program is funded by a consortium of industrial associates comprising the following companies: Amoco Production Company, ARCO Exploration and Production Technology, BP International Limited, Chevron Petroleum Technology Company, Exxon Production Research Company, Intevep S.A., Japan National Oil Corporation, Maxus Energy Corporation, Onyx 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, and Landmark Graphics Corporation via the Landmark University Grant Program.

Applied Geodynamics Laboratory

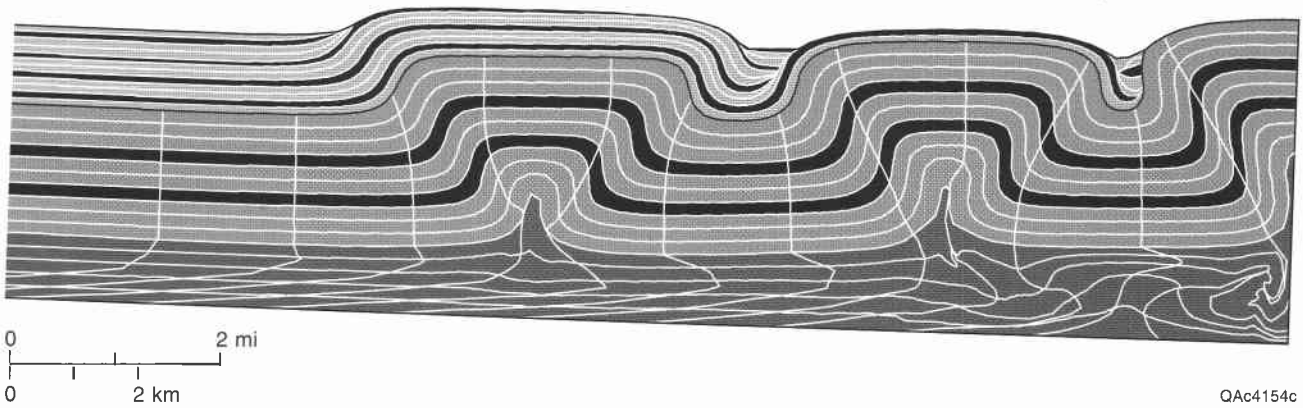
Martin P. A. Jackson, principal investigator;
Bruno C. Vendeville, laboratory manager;
Daniel D. Schultz-Ela and Giovanni Guglielmo, Jr.;
assisted by Joel H. Le Calvez, Ryan J. Mann, Shouan Tang, and Patrick Walsh

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.; Amerada Hess Corporation; Amoco Production Company; Anadarko Petroleum Corporation; BHP Petroleum (Americas) Inc.; BP Exploration Inc.; Chevron Petroleum Technology Company; Conoco Inc.; Elf Aquitaine; Exxon Production Research Company and Exxon Exploration Company; Marathon Oil Company; Mobil Exploration and Producing Company; Norsk Hydro; PanCanadian Petroleum Limited; Petroleo Brasileiro, S.A.; Phillips Petroleum Company; Saga Petroleum ASA; Shell Oil Company; Statoil; Texaco Inc.; TOTAL Minatome Corporation; and Vastar Resources Inc.

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 specifically for 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. Structural evolution is recorded by automatic cameras, including time-lapse video. Three-dimensional structures are mapped and visualized directly from the physical model by computer tomography or by reconstructing serial vertical sections. 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) sedimentary loading and evacuation of an allochthonous sheet, (2) basin-scale salt tectonics driven by sediment progradation, (3) formation and evolution of graben relays, and (4) remobilization of depocenters and dormant salt ridges by subsequent tectonics.

Numerical modeling and computer visualization require several Macintoshes and digitizers and two workstations. Three-dimensional mathematical simulation by means of Abaqus combines brittle and ductile deformation, large strains, and faulting. The following topics were systematically investigated: (1) control of synkinematic sedimentation and salt interbeds on structural



Computer model of the mechanical evolution of box folds in sedimentary rock (alternating black and light-gray layers) overlying salt (dark-gray body at the bottom). The entire model tilted 2° to the right and shortened at a rate of 10 mm/yr. The white lines are passive markers that were initially parallel and perpendicular to the base of the model. Thinner layers above the black line were deposited at 2 mm/yr as the folds grew. Their onlap surfaces on the upslope limbs of the folds record the initiation time of each fold in the upslope propagating train. The marker lines in the salt record early flow of salt into the core of growing folds and then late expulsion as the folds tightened.

style of thin-skinned contraction above salt and (2) evolution of grabens by thin-skinned gravity gliding above autochthonous salt.

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) break-out 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 seismic data, focusing on (1) the role of subaerial volcanism and major unconformities in the creation of the South Atlantic margins; (2) salt-tectonic provinces near the continental-oceanic boundary of the Lower Congo Basin (both with TOTAL); and (3) growth synclines and quantification of extension over basement steps in the southern Kwanza Basin, Angola (with BHP Petroleum).

Seismic Vector-Wavefield Characterization of Complex Reservoirs

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

The purpose of this program is to develop technologies that image reservoirs using all components of the seismic wavefield. Research objectives 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 and two distinct shear (S) wave images that are commonly referred to as fast-S and slow-S images. By combining information from these three seismic images, more insight can be gained into petrophysical rock properties, pore structure, pore-fluid properties, sequence relationships, and spatial distributions of lithologies, fractures, and anisotropic properties of reservoir systems.

Thirty-two companies sponsored this seismic vector-wavefield research during the year. Through donations provided by these sponsors, the Bureau has continuous access to a fully equipped seismic crew that records 3-D, nine-component data over a variety of prospects and to data-processing centers that can create the required P and S images. More than 50 mi^2 of 3-D, nine-component seismic data were recorded over various study sites during the year.

Fracture Research and Application Consortium

Stephen E. Laubach, Randall A. Marrett (Department of Geological Sciences, The University of Texas at Austin) and Jon E. Olson (Department of Petroleum and Geosystems Engineering, The University of Texas at Austin), principal investigators

This industry-sponsored research consortium was founded in August 1998. The aim of the consortium is to understand and successfully characterize, predict, and simulate reservoir-scale structures. The focus is on fractures and faults. Such structures have worldwide importance

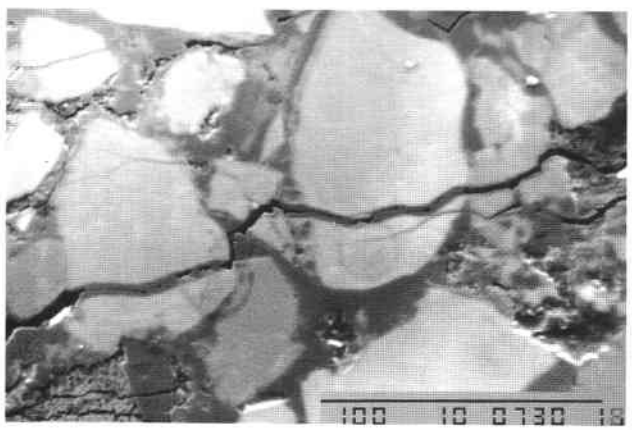
because of their influence on successful extraction of resources. Many faults and fractures are near or below the limits of seismic resolution or detection and are difficult or impossible to characterize adequately using currently available technology. Consequently, fractured reservoirs have been intractable to describe and interpret effectively, posing serious challenges for effective and accurate reservoir exploration and development.

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

New Methods of Natural Fracture Characterization

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

Advances in analysis of naturally fractured reservoirs—and other reservoirs where the role of natural fractures has been overlooked—have been achieved by means of powerful new scanning-electron-microscope-based imaging devices, quantitative descriptions of how structures of differing scales are related, and innovative geomechanical modeling techniques. This project, supported by Chevron U.S.A. Production Company; Conoco, Inc.; Exxon Production Research Company; Mobil Technology Company; Sanchez Oil & Gas Company; Tom Brown, Inc.; and Union Pacific Resources; (in addition to in-kind support from Oxford Instruments), aims to test and perfect these methods in active oil and gas plays.



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New imaging technology developed at the Bureau helps reveal microfractures that were previously invisible when using conventional observation methods. These small fractures can be used as proxies for large fractures that are difficult to sample. Their orientation matches those of large fractures in the same well, and their size-distribution patterns provide evidence of patterns of larger fractures. Microfractures were imaged by scanning-electron-microscope-based cathodoluminescence. Bar scale = 100 mm. Photo by Stephen E. Laubach.

Domestic Programs

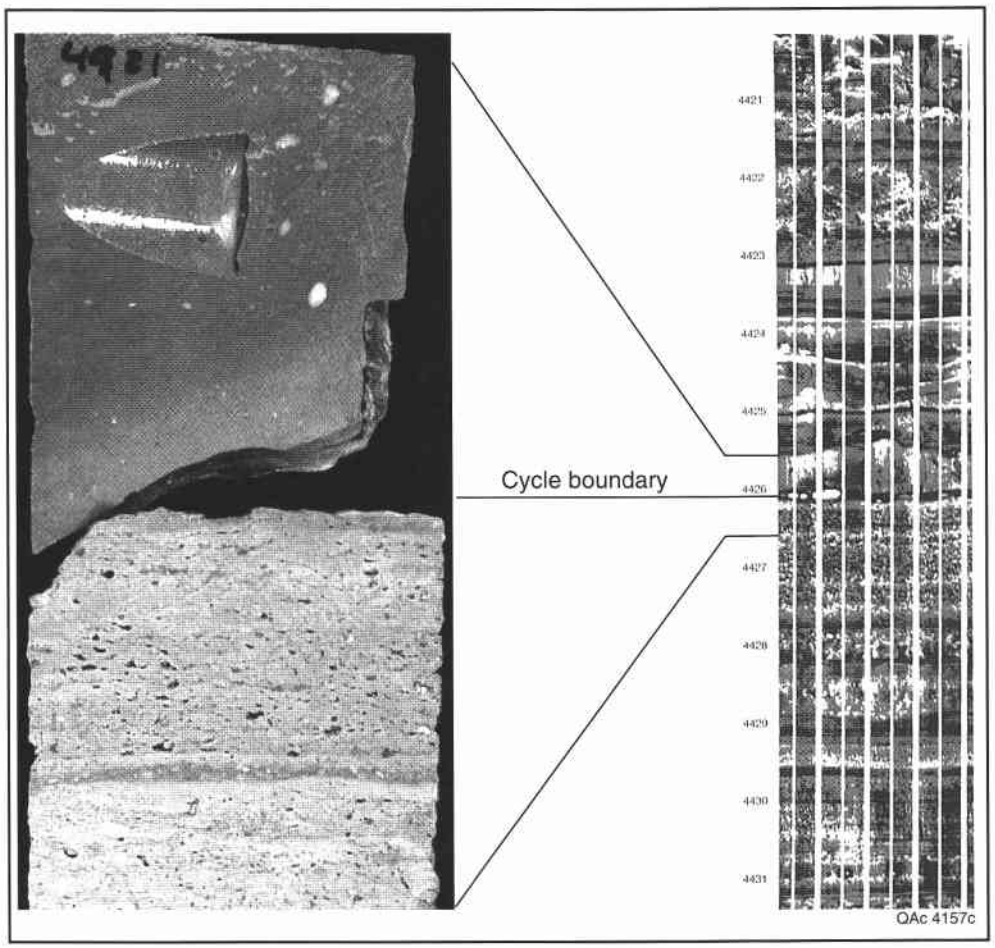
University Lands Advanced Recovery Initiative

Stephen C. Ruppel, principal investigator; Roger J. Barnaby, Jubal G. Grubb, Michael V. DeAngelo, Steve J. Shi, and R. P. Major; assisted by Russ K. Johnson, J. Greg Ramirez, Jose I. Guzman, and Cengiz T. Vur

This project is funded by The University of Texas System and by matching funds from operators of fields on University Lands. The goal of the University Lands Advanced Recovery Initiative is to characterize selected University Lands reservoirs and recommend new strategies for incremental recovery of the large remaining-oil resource on University Lands leases. A major factor in the selection of candidate reservoirs is a strong commitment by the operators to gather new data and to follow up studies with aggressive drilling and recompletion programs.

Two reservoir studies have been completed: (1) the Fuhrman–Mascho Block 10 San Andres–Grayburg Unit, a carbonate and siliciclastic reservoir, currently operated by Lomak Petroleum Inc. in Andrews County, and (2) University Waddell Devonian field, a Devonian chert reservoir in Crane County, which is operated by Pennzoil.

The Fuhrman–Mascho study shows that the reservoir is composed of three distinctly different flow-unit regimes, each requiring distinctly different approaches to drilling, recompletion, and water flooding: (1) relatively continuous and high-permeability siltstones in the Grayburg Formation, (2) generally low and highly discontinuous permeability in tidal-flat carbonates of the upper San Andres Formation, and (3) variable but continuous unconformity-related permeability development in outer-ramp carbonates of the lower San Andres. An important contribution of this study was the documentation of the use of borehole imaging logs in identification and correlation of carbonate facies



When calibrated to core, borehole-imaging logs provide crucial information on reservoir fabric and architecture that is exceeded only by continuous whole core. Here, the boundary between a cycle-capping tidal-flat facies and cycle-base wackestone is clearly defined. Permian San Andres Formation, Fuhrman–Mascho field, Andrews County, Texas. Core photo by Stephen C. Ruppel.

and cyclicity. These logs proved critical in constraining reservoir facies architecture and permeability. The current operator has used the results of the study to design further development of the field.

In the Devonian chert (Thirtyone Formation) reservoir at University Waddell field, careful study and correlation of cores and logs have led to a much improved understanding of the reservoir stratigraphy and architecture. This work shows that the reservoir is composed of numerous petrophysically separate chert porosity zones that are both vertically and horizontally discontinuous. The discontinuities explain the relatively poor recovery efficiency during both primary and secondary development. Many wells contain high-porosity zones that have not yet been tested. The study recommends specific targets for drilling, completion, and recompletion that are designed to develop incremental oil production from previously uncontacted reservoir zones. The techniques used to improve Waddell reservoir characterization have direct application to other Devonian chert reservoirs in the Permian Basin.

Three additional reservoirs are now under study: (1) the North McElroy Grayburg reservoir in Crane and Upton Counties, operated by Apache Corporation; (2) the Pennsylvanian Unit, operated by Cross Timbers, at Block 9 field in Andrews County; and (3) the Wolfcamp Unit, also operated by Cross Timbers, at Block 9 field.

The North McElroy Grayburg reservoir, despite being under production since 1926 and having more than 600 wells, contains a huge remaining mobile-oil resource of more than 200 million barrels. Study of this dolostone reservoir shows that a fundamental problem is the lack of a robust method of defining reservoir petrophysics because of the presence of gypsum. Comparison of core and wireline-log data shows that standard neutron-density wireline-log measurements exhibit no relationship to true porosity. A major thrust of this study is to develop an improved model of porosity distribution in the reservoir as a basis for targeting remaining oil.

Both the Pennsylvanian and Wolfcamp reservoirs in Block 9 field have exhibited very poor response

to waterflood. Early study shows that in addition to comprising highly cyclic and laterally discontinuous facies, both limestone reservoirs are significantly overprinted by diagenesis associated with karsting produced during frequent sea-level falls. Wireline-imaging logs have proven to be a fundamental tool in both reservoirs for defining cyclicity, facies, rock fabrics, and karst. Preliminary examination of geophysical data suggests that the complex faulting of the Pennsylvanian may also contribute to the poor primary and secondary recovery in the reservoir. A fundamental element of the study includes analysis and interpretation of the 3-D geophysics to determine what role structural compartmentalization plays.

Application of Advanced Reservoir Characterization, Simulation, and Production Optimization Strategies to Maximize Recovery in Slope and Basin Clastic Reservoirs

Shirley P. Dutton, principal investigator; Mark D. Barton and Mohammad A. Malik; assisted by Luciano L. Correa and Jose I. Guzman

This study of deep-water turbidite sandstone reservoirs is funded by the U.S. Department of Energy as part of the Oil Recovery Technology Program for Class III (slope and basin clastic) reservoirs. 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 the original oil in place through strategic placement of infill wells and geologically based field development. Project objectives are divided into two main phases. The original objectives of the reservoir-characterization phase of the project were to (1) provide a detailed explanation of the architecture and heterogeneity of two representative fields of the Delaware Mountain Group, Geraldine Ford and Ford West, which produce from the Bell Canyon and Cherry Canyon Formations, respectively; (2) choose a demonstration area in one of the fields; and (3) simulate a CO_2 flood in the demonstration area. Results indicated that 10 to 30 percent (1 to 3 million barrels [MMbbl]) of remaining oil in place in the demonstration area can be produced by CO_2 injection.

A new industry partner, Orla Petco, Inc., will participate in the next phase of the project, which includes an extensive field demonstration to be conducted in East Ford field. This field, immediately adjacent to the Ford Geraldine unit, produces from the same Ramsey sandstone channel. The reservoir-characterization phase of the project has been expanded to include East Ford field. This additional reservoir-characterization task provides an excellent opportunity to test the transferability of the geologic model and log-interpretation methods developed during reservoir characterization of the Ford Geraldine unit to another Delaware sandstone field.

The objectives of the implementation phase of the project remain the same, to (1) apply the knowledge gained from reservoir-characterization and simulation studies to increase recovery from a demonstration area, (2) demonstrate that economically significant unrecovered oil can be recovered by a CO_2 flood of the demonstration area, (3) test the accuracy of reservoir characterization and flow simulation as predictive tools in resource preservation of mature fields, and (4) evaluate transferability of the geologic model to other fields. The goal is to develop a geologically designed CO_2 flood and well-completion program in a representative Delaware sandstone field that can serve as a model for other fields in the play. Through technology transfer, the knowledge gained in this study can be applied to increase production from more than 100 other Delaware Mountain Group reservoirs.

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

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.

The study has demonstrated the fidelity of GPR for resolving different scales of geologic variation. Using various antenna (50-, 100-, and 200-Hz) and sampling strategies, we focused on detecting geologic variation across scales from individual depositional beds to kilometer-long changes in radar facies across transitions between different depositional environments. GPR was found to work best in resolving meter-thick bedding in sandstone-dominated deposits to depths of 7 to 15 m. For example, profiles across fluvial sandstones clearly showed channel-bar and -fill deposits and some of 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.

State of Texas Advanced Resource Recovery (STARR) Project

Roger Tyler, principal investigator; Roger J. Barnaby, Sigrid J. Clift, Shirley P. Dutton, H. Scott Hamlin, Douglas S. Hamilton, Mark H. Holtz, Stephen E. Laubach, Mark R. Vining, and Wan Yang; assisted by Ke Sheng Chan, Jianchun Dai, Toribio A. Jimenez, Hye Won Kim, Jorge L. Marchan, Han-Ching Wu, and Tiejun Zhu

The State of Texas Advanced Resource Recovery (Project STARR) Project is conducting a multiyear analysis of oil and gas fields on Texas State Lands that so far indicates that proved reserves (oil that will be produced using currently deployed technology) total only 270 million barrels (MMbbl). This figure compares with the 3.43 billion barrels (Bbbl) of oil that is projected to remain at reservoir abandonment, 1.6 Bbbl of which is mobile oil. The amount of mobile oil that will be foregone unless advanced geological and engineering technology continues to be applied to State Lands reservoirs therefore nearly equals the cumulative production to date. A similar picture emerges for natural gas in Texas State Lands fields. Cumulative gas production is 10 trillion cubic feet (Tcf). The amount of natural gas remaining in the largest State Lands gas reservoirs is, however, estimated to be another 10 Tcf. The amount of natural gas projected to remain unrecovered at reservoir abandonment under currently deployed technology thus equals the amount of gas produced to date. Clearly, with regard to in-place volumes of oil and gas, State Lands reservoirs are nowhere near depletion.

With funding from the State of Texas and with support from the General Land Office and Railroad Commission of Texas, Project STARR is designed to capture a substantial part of this large volume of unrecovered oil and gas remaining in State Lands fields. Bureau researchers, in collaboration with Texas operators, have studied 11 State Lands fields. Optimization of oil- and gas-recovery strategies has resulted in characterization and deployment of advanced recovery technologies in several key reservoirs and the transfer of concepts and approaches in recovery optimization to other State Lands operators. To date, detailed geologic and engineering characterization has created (1) quantitative reservoir descriptions, including identification and distribution of untapped and bypassed compartments and zones of remaining oil and gas, and (2) various designs of optimized recovery strategies, including stepout wells, well deepening, recompletions, workovers, targeted infill drilling, injection profile modification, and waterflood optimization, all of which have added to the recoverable oil and gas reserve base remaining on State Lands. Project STARR has recommended 56 infill wells, 56 recompletions, and 3 stepout wells over the project's 4-year duration. To date, at least 39 infill wells and 29 recompletions have been drilled on State Lands on the basis of STARR recommendations, with a total royalty revenue to the Texas Permanent School Fund estimated to exceed $7.1 million, directly benefiting the schoolchildren of Texas. Texas State Lands operators are invited to participate in Project STARR by contributing data to the Bureau in exchange for expert technical assistance in developing State Lands oil and gas fields.

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

Robert J. Finley, principal investigator; Tucker F. Hentz; assisted by Ramiro Amaya

The Bureau has been working to improve natural gas recovery efficiency in complex onshore reservoirs since 1988. Research on onshore Gulf Coast sandstones, sandstones of the

Fort Worth Basin, and karsted carbonate reservoirs of the Permian Basin has successfully defined secondary, or incremental, gas recovery that is based on targeting reservoir heterogeneity. These heterogeneities have largely been stratigraphic and diagenetic rather than structural, given that fault compartmentalization of reservoirs is a well-known barrier to completing hydrocarbon recovery. At present, with funding support from the U.S. Department of Energy, the Bureau is teaming up with Texaco, Inc., to evaluate reserve growth potential in the Federal offshore of the Gulf of Mexico.

The Bureau has begun evaluating Starfak, North, and Starfak fields in the Vermilion Block 30 area. The study also includes the adjacent acreage in Tiger Shoal field, which has a middle Miocene section that includes multiple fluvial and deltaic reservoirs vertically stacked between 7,000- and 12,000-ft drilling depths. The area has 3-D seismic coverage, and all available data on the area are being incorporated into a digital data base in the start-up phase of the project. The objective will be to evaluate the causes and styles of heterogeneity that have led to additional natural gas development in this field.

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

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

As a part of their research to develop seismic vector-wavefield technology for reservoir characterization, the staff of the Bureau's Exploration Geophysics Laboratory conducted field work to develop and test new seismic vector-wavefield energy sources that are appropriate for geothermal prospects. This research was funded by the Geothermal Division of the U.S. Department of Energy.

Two new vector-wavefield seismic sources were developed as the result of this research: (1) a vector-explosive package that can be deployed in conventional seismic shot holes and (2) paired vertical seismic vibrators made to function as two-element dipoles rather than as conventional two-element monopoles. Experimental field tests were conducted in South Texas, West Texas, Montana, Pennsylvania, and Oklahoma during the course of the investigation. The vector-explosive source developed in this program is manufactured by Austin Powder Company and is commercially available for shear-wave seismic imaging of both geothermal and oil and gas reservoirs.

Devine Geophysical Test Facility

Bob A. Hardage, Robert J. Graebner, and Milo M. Backus, principal investigators; Donna G. Cole

British Petroleum (BP) donated a 100-acre site near Devine, Texas, to the Bureau that is ideal for seismic field experimentation. This Devine Test Facility has three cased wells that in 1987 were drilled through the Austin Chalk (~3,000 ft deep) specifically for the purpose of borehole geophysics research. BP did considerable testing of crosswell seismic technology in these wells for several years, and logging contractors have used the site numerous times to test and calibrate new logging devices. A large number of these historical test data were included in the donation.

The Society of Exploration Geophysicists provided funding to assist in cataloging the historical data, to make physical improvements to the site that will allow easier access by students and academic researchers, and to prepare publicity describing how academe and industry can use the test facilities. Information about the Devine Test Site can be found on the Bureau's Web site, http://www.utexas.edu/research/beg/, under the Geophysics Program, http://www.utexas.edu/research/beg/geop.html.

Petroleum Technology Transfer Program

Andrew R. Scott, principal investigator; L. Edwin Garner and Tucker F. Hentz; assisted by Kimberly High

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. Funded primarily by the National Petroleum Technology Office (NPTO) and the Federal Energy Technology Center (FETC) of the U.S. Department of Energy (DOE), Office of Fossil Energy, the main tasks of PTTC include (1) identifying the technological problems of United States oil and gas producers and communicating these needs to the research and development community and (2) transferring to domestic producers new and existing upstream technologies

that will help them reduce finding costs, improve operating efficiency, improve ultimate recovery, enhance environmental compliance, and add to domestic oil and gas reserves.

The technical information that the PTTC transfers to producers comes from all sectors of the research and development community and intermediary providers of technology, including government, universities, 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 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; resource links; and exploration, production, research, and development forums. Workshops are an important part of the technology-transfer process, and during the past year the PTTC Texas Region sponsored 26 cooperative and focused technology workshops attended by more than 2,300 participants.

The Railroad Commission of Texas (RRC) and the Texas PTTC office co-sponsored a series of oil- and gas-production-incentive and technology-transfer seminars that were held in each major RRC district in the state. These seminars were designed to encourage exploration and production, particularly by independent oil and gas operators. The objectives of the 3-hour seminars were to help reduce operating costs through the application of new and existing technologies and to encourage the incorporation of severance-tax incentives into operating and business plans.

The PTTC also co-sponsored workshops summarizing the results of a multidisciplinary study of Ellenburger natural gas reservoirs in Lockridge, Waha, and Waha West fields and parts of Worsham–Bayer and Cayanosa fields of the southern Delaware Basin, West Texas. These workshops, held in Midland and Houston, were designed to acquaint geologists, geophysicists, and petroleum engineers with advanced 3-D seismic, production, and petrophysical analysis to help define the location and controls on gas production from the deep Ellenburger play of the Permian Basin. Short-course participants received a CD-ROM containing approximately 20 mi^2 of 3-D seismic data that illustrate the structural complexity of the area. Workshops focusing on the geological, geophysical, and engineering aspects of naturally fractured reservoirs were also conducted in Midland and Tyler, Texas.

Secondary Natural Gas Recovery in the Appalachian Basin: Application of Advanced Technologies in a Field Demonstration Site, Henderson Dome, Western Pennsylvania

Bob A. Hardage and Andrew R. Scott, principal investigators; James L. Simmons, Jr., Stephen E. Laubach, and Randy L. Remington; assisted by Eloise H. Doherty

The Bureau of Economic Geology was the principal subcontractor to the West Virginia University Research Corporation in a program funded by the U.S. Department of Energy to develop technology that can be used to improve operator drilling success in fracture-controlled gas reservoirs in the Appalachian Basin. The focus of the research was investigation of technologies that will allow Appalachian operators to detect and evaluate fractured reservoir facies.

A major finding of the research was that characteristics of grain-scale microfractures observed in thin-section analysis of sidewall cores can be used to predict critical properties of reservoir-scale fracture systems. Seismic field tests were also conducted during the project to establish how to best generate seismic shear (S) waves over Appalachian Basin prospects because S waves are particularly sensitive to fractures. These field tests demonstrated that the new vector-explosive source developed by the Bureau's Exploration Geophysics Laboratory generates good-quality S waves in the Appalachian Basin and that conventional seismic sources generate robust converted-mode S waves at basinwide formation interfaces that lie above the major gas-producing reservoirs.

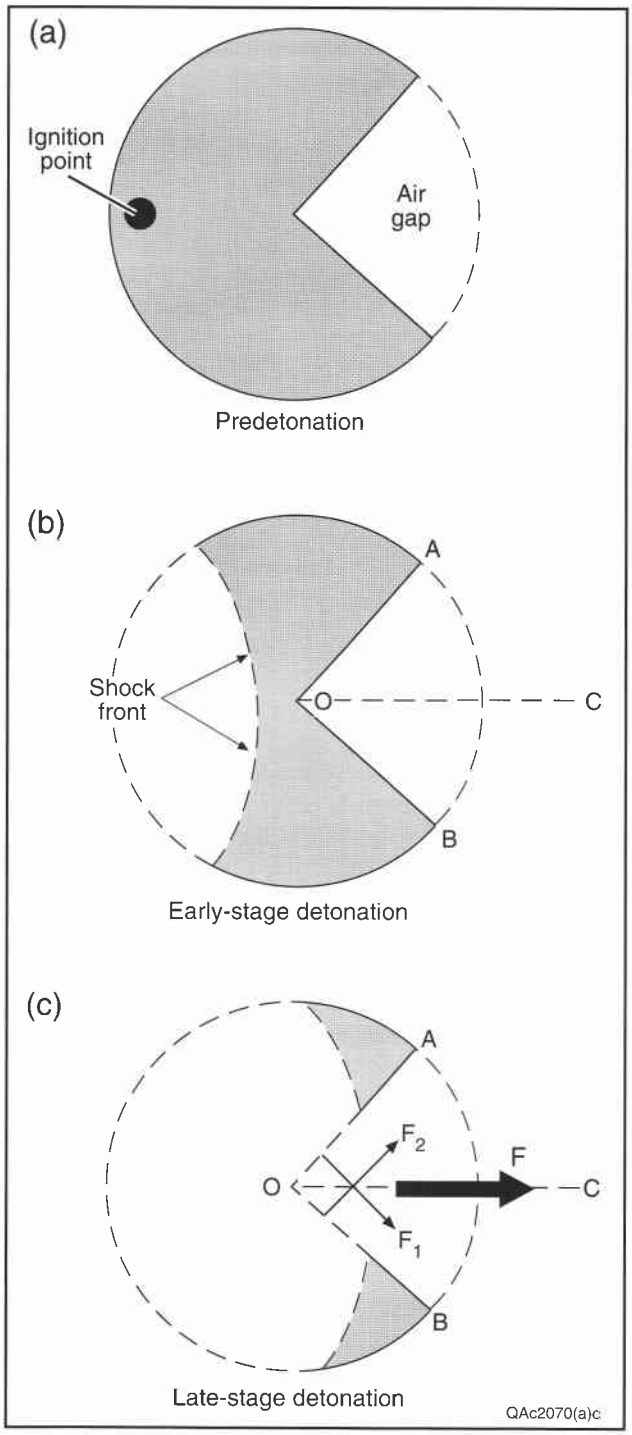


Diagram showing stages of detonation of directional, shaped-charge, seismic explosive package developed by Bureau researchers for the Henderson Dome study. This package allows operators to generate seismic S-waves (essential for detection of fractured reservoir facies) in prospect areas where conventional S-wave sources cannot be used. The overhead view in the diagram allows us to look down on the shaped charge as it proceeds through three stages of detonation. The detonation front is created at (a) an ignition point that is directly opposite (b) the shaped notch BOA. As the shock front sweeps past (c) the notch, it creates counteropposed forces F_1 and F_2 that sum as vectors to create a strong horizontal force, F. The shaped notch extends the full length of the cylindrical charge.

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)

The Bureau has developed a basin-scale producibility model for defining areas of prolific coalbed methane production on the basis of a decade of research performed in the Rocky Mountain Foreland, western United States. As part of a cooperative agreement between the Bureau and the Division of Geological and Geophysical Surveys, Department of Natural Resources, State of Alaska, this producibility model was applied to the evaluation of coalbed methane resources in rural Alaskan coal provinces and basins. The cooperative agreement resulted in evaluation of the coalbed methane resources of rural Alaska by our selecting coalbed methane exploration basins for the purpose of drilling and testing their potential as an alternative rural energy source to be used for local electrical power generation and home heating. Although Alaska's potential for coalbed methane resources may be as high as 1,000 trillion cubic feet, the actual number of methane-bearing coal basins and resources is still mostly unknown and the extent and magnitude of producible gas remain untested.

Bureau researchers used basin-analysis concepts to define an exploration fairway along the western North Slope that has high coalbed methane producibility potential. Along the western North Slope and within the Colville Basin, the mechanism for coalbed methane resource development is conventional and hydrodynamic trapping. The traps are postulated to be both stratigraphic and structural, and an exploration fairway has been defined between the villages of Wainwright and Atqasuk and in an area 30 mi south of these villages. Analysis by Bureau researchers indicates that the stratigraphic traps are related to updip (northeast) pinch-out of the coal beds behind the progradational shoreline sequences of the coal-bearing Nanushuk Group on the south flanks of the Barrow Arch and west of the Meade Arch. Structural traps within this area will consist of fault-cored anticlines related to the Rocky Mountain Foreland (Brooks Range and Barrow Arch) orogenesis and gas traps formed against smaller displacement faults. Moreover, the updip migration of thermogenic gases within the thick, laterally continuous coal beds and the trapping of the migrated gases beneath permafrost layers (clathrate development) must also be considered as exploration targets in combination

with the methane-resource development along the defined exploration fairway. Coal ranks in the Colville Basin are high enough for favorable coalbed methane resource development, approaching the high-volatile A bituminous coal ranks at depths of less than 6,000 ft. Evidence of some saline water beneath the permafrost suggests that meteoric recharge from the Brooks Range may not have penetrated this far north. Gases in this area could therefore be predominantly thermogenic and migrated thermogenic, although secondary biogenic gases may be present locally. Additional subsurface hydrologic characterization and additional water geochemistry data should be collected to establish the extent of the saline aquifer and to characterize ground-water attributes. The next phase in the development of coalbed methane resources of rural Alaska will be the drilling and testing of the defined exploration fairway.

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

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

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

Although there is a wide range in natural gas URG potential by play, which is a function of the drilling and technology applied, current natural gas URG studies are too general, having wide-range averages that are disaggregated by broad natural gas provinces and calculated solely as a function of time.

The primary research objectives of this project, funded by the U.S. Department of Energy, are to develop new concepts in (1) realistic and play-specific measures of remaining natural gas URG potential, (2) assessing the technology necessary and most amenable to realizing natural gas URG, and (3) assessing economic factors involved in realizing natural gas URG in the Gulf Coast Basin. Through such assessment, the long-term potential and economics of natural gas URG as a contributor to the future natural gas supply from the Gulf Coast Basin can be determined and quantified.

The Texas Railroad Commission of Texas (RRC) District 4 was initially reviewed and analyzed. The district was selected on the basis of its role as a major natural-gas-producing district in the Gulf Coast Basin, where significant technological advancements have been routinely applied and its historical production data maintained on a reservoir level. A total of 520 major fields were selected for analysis in RRC District 4. These fields were allocated initially into 18 geologically defined plays. Because of limited URG data, only 11 plays were selected for detailed analysis. Natural gas URG analysis on the basis of time and drilling activity was performed on all 520 major fields and on the selected 11 individual natural gas plays of RRC District 4. Significant URG and future potential were calculated for these major fields.

Important natural gas URG data were, however, masked by such a total, aggregated analysis. The play-by-play analysis revealed more natural gas URG trends. Plays WX-2 (Lower Wilcox Lobo Trend), WX-4 (Wilcox Deltaic Sandstones in the Rio Grande Embayment), and VK-1 (Vicksburg Deltaic Sandstones in the Rio Grande Embayment), the top three plays experiencing natural gas URG, hold the largest future potential. These three plays also had the three highest yields, when considering only recent natural gas URG data from 1977 to 1993. Semiquantitative correlation with a high degree of structural complexity, tight gas sandstones, high reservoir pressures, and deep reservoirs were identified for these three plays. Plays MC-1 (Miocene Deltaic Sandstone in the Rio Grande Embayment) and MC-2 (Miocene Fluvial Sandstone in the Rio Grande Embayment) were, on the other hand, shown to have little to no natural gas URG potential.

Future efforts will involve delineating the technologies to be applied and those that will be most amenable by play. Furthermore, an economic evaluation of these technologies from

an engineering perspective by means of a cost-benefit analysis, as well as specific case studies of individual fields and reservoirs experiencing significant natural gas URG potential, are important tasks remaining to be undertaken. The methodology of such an assessment will be verified and applied more broadly to other Gulf Coast Basin natural gas resource areas having significant natural gas URG potential.

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

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

The goals of this project, funded by the Advanced Research Program of the Texas Higher Educational Coordinating Board, include characterization of fracture arrays in carbonate strata and relating the fracture characteristics to fluid-flow observations and bedding architecture of the sedimentary rocks. One study area for this project is in the Sierra Madre Oriental mountains of northeastern Mexico, the field campaign for which took place in October 1998. Results of outcrop analyses will be compared with analogous work on core extracted from petroleum wells. We have obtained core samples and associated oil-production data for two wells from Petróleos Mexicanos (PEMEX) and completed initial fracture characterization. A pilot study of fracture scaling in carbonate outcrops of Central Texas is also complete. The pilot study has confirmed that fracture apertures in limestone follow power-law scaling across at least four orders of magnitude, comparable to what our previous work demonstrated for sandstone. These results have implications for targeting and simulating fractures in carbonate reservoirs.

Geologic Characterization of Fractured Reservoir Block Size Using Microcrack Data

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

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

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 Joy D. Griffin, Yaguang Gu, Faustino Monroy, Javier G. Moros, Orlando J. Ortega, Yuan Qiu, Adam J. Schwartz, and Robert M. Reed

Despite the critical role natural fractures commonly play in governing reservoir fluid flow, fractures are rarely accounted for adequately in reservoir simulations. This oversight results not only from 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, and implemented through BDM–Oklahoma, Inc., developed fracture characterization approaches and methods for incorporating this information into fractured reservoir simulators. It was 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 1998, the research team successfully integrated fracture characterization and evaluation methods developed during the project in several case studies and presented results in workshops in Austin, Midland, and Denver. The project, which ended in September 1998, resulted in several conceptual and practical breakthroughs in fracture analysis.

Gulf of Mexico Subsalt Structure Study

Martin P. A. Jackson, principal investigator

Funded by Agip Petroleum, this project investigated structures below allochthonous salt over a wide area of the Louisiana shelf and upper slope. The project, based on interpretation of 2-D reflection seismic data recorded to 15-second two-way time, has aimed at improving geodynamic understanding of salt tectonics and salt systems in this region, especially the relation between subsalt structures and suprasalt structures and the underlying basement. The regional tectonic framework developed by the project has provided a context for and improves understanding of individual prospect-scale structures. The project resulted in maps of structural provinces and main structural elements, regional seismic profiles, criteria for seismic interpretation, an atlas of suprasalt and subsalt structures, and a tectonic synthesis with potential field data. This project was completed with a final report.

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

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

The Grabens area of Canyonlands National Park, Utah, records the interaction of propagating extensional faults that today are still slipping above a layer of flowing salt. Erosion of the Colorado River canyon down to the salt layer has allowed stretching and gravity gliding of the overburden down the gentle regional dip. Numerical modeling of this uniquely well constrained fault system will enhance understanding of brittle rock stretching above a ductile layer in other parts of the world. Our two-dimensional computer models of the evolution of The Grabens have tightly constrained the cross-sectional geometry of the faulting and the material properties of the rock. Field work indicates that displacement varies along the faults and extension transfers from one fault system to another. The remainder of the project, funded by the Advanced Research Program of the Texas Higher Educational Coordinating Board, involves three-dimensional numerical modeling to simulate how the faults initiate, propagate, and interact. Modeling of this type of brittle–ductile system has not been previously done. Field work in The Grabens area will provide the accurate input data necessary for meaningful finite-element modeling. The results will clarify extensional processes in other areas of the world having similar, but more complex, evolutions. Examples of such areas are the Gulf of Mexico, North Sea, Basin and Range, East African and Rio Grande rifts, midocean spreading centers, and grabens on other planets and moons.

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Oblique aerial view of The Grabens in Canyonlands National Park, Utah, looking south. The Colorado River (right) has cut through the sedimentary rock lying on top of weak salt, allowing the overburden to creep downdip to the right. This extension has created the series of grabens that appear as narrow, linear valleys in the photo. Photo by Daniel D. Schultz-Ela.

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

Revised concepts of salt deformation combined with technological advances have rejuvenated oil exploration in the Gulf of Mexico, but 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 investigated the effect of sediment loading and salt-sheet geometry on the structural development around salt sheets. Modeling by unique, state-of-the-art finite-element software allowed variation of density, strength, geometry, salt viscosity, and deposition patterns and rates. Examining the effects of each variable revealed the critical controls on deformation and, therefore, the evolution of migration pathways and traps needed for hydrocarbon accumulation.

We systematically varied a wide array of properties to explain the mechanics of sediment loading and salt-sheet deformation. A number of key findings

emerged. (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. (4) An inclined diapiric stem feeding the sheet collapsed as a sheet inflated, causing uplift of the salt roof rather than the subsidence found in other models. Presence of a feeder substantially changed the results in runs varying location and rate of sedimentation, regional slope, regional extension, initial salt bulge, and sediment density. (5) 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. (6) Low sedimentation rate favored development of a roho fault system, whereas a steep depositional slope and undercompacted sediment favored a stepped-counterregional system.

International Programs

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

Robert J. Finley, principal investigator; Paul R. Knox, Jirapa Skolnakorn, Robert E. Barba, Jr., Eric von Lunen, Mary L. Mercer, Christine R. Martinez, Matthew P. Mahoney, Joseph S. Yeh, Ronald L. Russell, Courtney Michelle, and Dallas B. Dunlap; assisted by Jinghua Chen and Ke Sheng Chan

The Bureau is working on behalf of OMV Aktiengesellschaft to help define the remaining unrecovered oil and gas resource in Matzen field, the largest oil and gas field in Central Europe, located about 30 km northeast of Vienna, Austria. Well deepening, well recompletions, and, potentially, infill drilling based on integrated reservoir characterization are all under consideration as parts of this study. After completing an overall genetic stratigraphic framework, we have focused on dividing existing stratigraphic units of the Badenian (middle Miocene) into a series of layers representing fourth- and fifth-order sequences. Some of the most important reservoir intervals, such as the 8th Badenian and the 9th Badenian, have been subdivided into four and six layers, respectively. Channel and mouth-bar deposits and adjacent splay deposits are prevalent in the 8th and the 9th, with additional progradational delta-front deposits in the 9th. Below the 9th, delta-front and slope fan deposits are important parts of the 11th, 12th, and 13th Badenian.

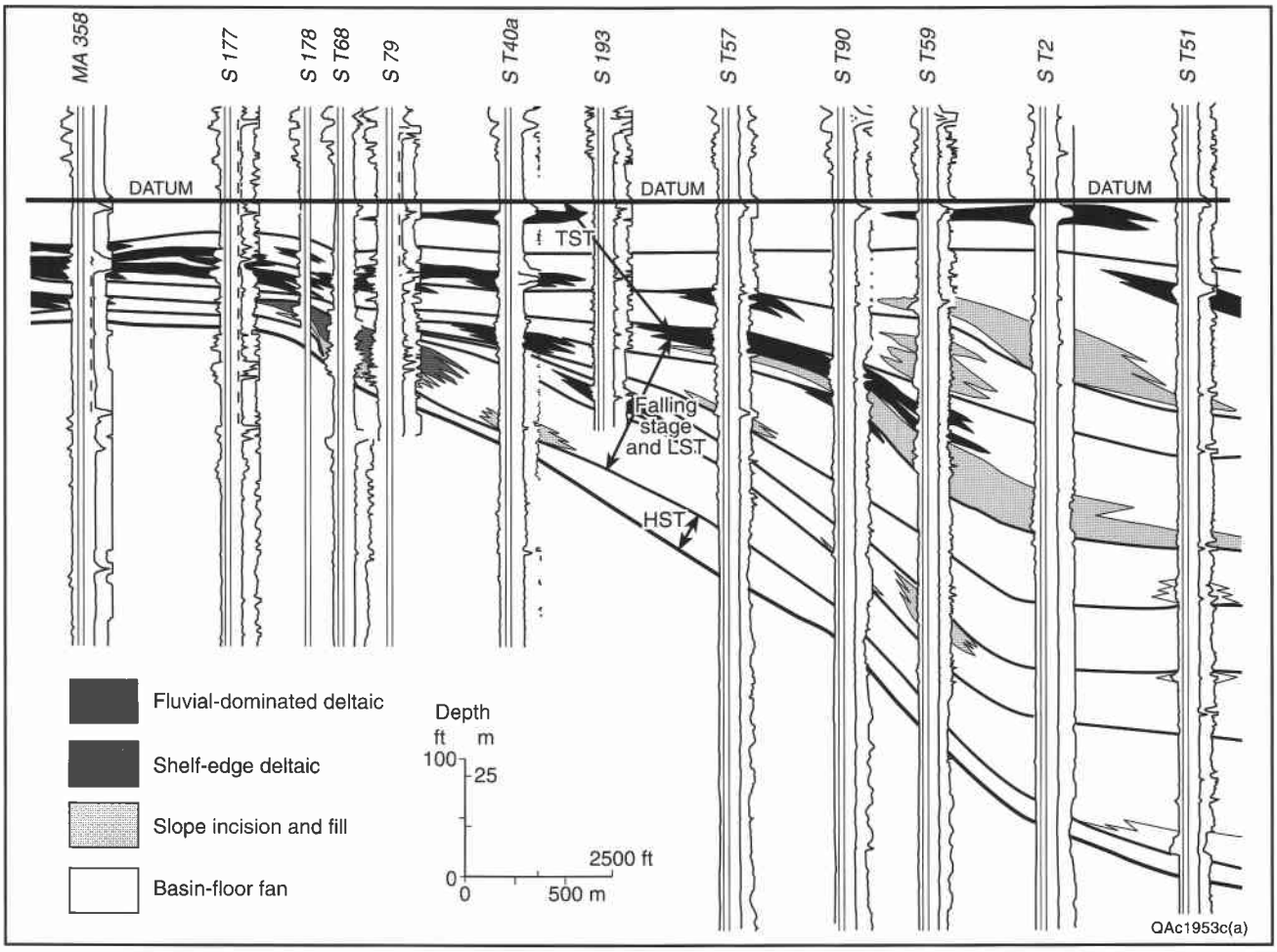
Much of our recent work has focused on the tectonics of the Vienna Basin. Interpretation of 3-D seismic has shown sinistral strike-slip deformation leading to a series of shears and extensional duplexes that have generally north to northwest trends. These features are seen on sections through the original seismic volume as linear features having little or no offset. They are more clearly seen on interpreted horizons through continuity volumes, where linear discontinuities are interpreted as faults having mainly strike-slip offset. We tested several potential traps related to these features in late 1998 by deepening three existing wells. Interplay between structure and sedimentation is seen in the transgressive bar and channel sandstones in the 11th Badenian, which are concentrated in an axial area of a buckled extensional duplex and are trapped behind northeast-trending, positive flower structures. These structures formed along shear systems that are thought to have formed an elevated shelf edge.

We completed geological work on the southern two-thirds of this 1,400-well field in late 1998 and will complete engineering work in early 1999. The most complex, normally faulted north part of the field remains to be assessed through mid-1999.

Integrated Geological and Geophysical Update of Proposed Drilling Locations for Miocene Sands and Reservoir Characterization, Simulation, and Exploitation Planning for the Eocene "B" Sands: Mioceno Norte Area, Lake Maracaibo, Venezuela

H. Scott Hamlin and William A. Ambrose, principal investigators; Shirley P. Dutton, Mark H. Holtz, Martha L. Romero, Mark A. Sparlin, and Robert E. Barba, Jr.; Regulo A. Alvarez, Rafael Mendoza, and Edgar Villalta (Petróleos de Venezuela, S.A.); George B. Asquith (Texas Tech University); assisted by Heon Cho, Luciano L. Correa, Erxiang Liu, Janaka B. Paulis, Mirtes C. Pessoa, and D. Scott Settemeyer

The goal of this 2-year project is to optimize production from Eocene and Miocene sandstone reservoirs by building on a successful study of the Mioceno Norte Area, which was completed in 1996 by the Bureau and Petróleos de Venezuela, S.A. (PDVSA). This new investigation, also undertaken jointly by the Bureau and PDVSA, integrates geological, geophysical, petrophysical, and



Stratigraphic well log cross section parallel to depositional dip in Matzen field, Austria, showing initial highstand, then falling stage–lowstand and, finally, transgressive high-frequency depositional units within a fourth-order reservoir package. Reservoir sandstones in this clinoforming package include fluvial-dominated deltaic, shelf-edge deltaic, slope incision-and-fill, and basin-floor fan-depositional settings. Improving our understanding of sandstone architecture is expected to increase ultimate recovery from this and other reservoirs in this supergiant field.

engineering characterization in order 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 million barrels (MMbbl) of oil since 1930. These reservoirs are, however, estimated to have a recovery efficiency of only 27 percent by the end of primary recovery operations. 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.

Eocene reservoirs are being characterized according to an integrated approach that includes well- and seismic-based stratigraphic and structural analysis, petrophysics, and reservoir engineering. In the Eoceno Norte Area, Eocene reservoirs all lie within "B member" sandstones of the Misoa Formation. Although most B-member sandstones are relatively thin (10 to 50 ft) progradational deltaic deposits, a few are massive (100 to 300 ft thick) fluvial deposits. The fluvial sandstones, which range from lenticular (B-7 member) to tabular (B-6 member), probably represent incised valley-fill deposits. Analysis of 3-D seismic data revealed a complicated, highly faulted setting where traps formed along an angular unconformity at the base of the Miocene.

For the Eocene reservoirs, petrophysical analysis of both old and new well log suites is being used to define reservoir flow units within the stratigraphic and structural framework. Maps are being constructed showing oil–water contacts, net pay, porosity, saturation, and hydrocarbon pore volume for each genetic stratigraphic unit. Well-test and production data are also being used

to map reservoir properties, remaining oil distribution, and production potential. Finally, a 3-D reservoir-simulation model is being constructed to integrate geologic and engineering data, verify reserve estimates, and forecast production from proposed development wells.

In the Miocene reservoir section, careful review of 3-D seismic and production data resulted in the identification of 11 high-priority wells, each estimated to contact more than 1 million stock-tank barrels of remaining oil, that were submitted to PDVSA for inclusion in the drilling schedule for 1998–1999.

Characterization of Eocene Reservoirs: Pilar Sur Area, Lake Maracaibo, Venezuela

Andrew R. Scott and William A. Ambrose, principal investigators; Robert E. Barba, Jr., Dallas B. Dunlap, Shirley P. Dutton, Douglas S. Hamilton, C. Robertson Handford, Mark H. Holtz, Janaka B. Paulis, Martha L. Romero, Mark A. Sparlin, and Ramón H. Treviño III; assisted by Danielle J. Cole, Erxiang Liu, Mirtes C. Pessoa, and D. Scott Settemeyer

This 22-month reservoir characterization of the Petróleos de Venezuela, S.A. (PDVSA), Pilar Sur Area, occupying a 20-mi^2 (51.8-km^2) area in north-central Lake Maracaibo, began in December 1997. The study is an integrated analysis that includes genetic sequence stratigraphy, 3-D seismic interpretation, petrophysics, petrography, and production engineering. The objective of the study is to provide PDVSA with a variety of new drilling opportunities to increase oil recovery from tidal-delta, tidal-shelf, and estuarine-fill deposits in the C Members of the Lower Eocene Misoa Formation.

Facies architecture and structural complexity in the Pilar Sur Area control the distribution and lateral continuity of reservoir compartments and areas swept by waterflooding. Primary recovery is expected to be less than 25 percent of the original oil in place, suggesting that optimizing recovery of the remaining oil resource will require an understanding of the structural and stratigraphic framework, as well as the fluid distribution.

Faults provide the main structural controls on reservoir architecture in the Pilar Sur Area, which occupies a structurally high area between two transpressional, left-lateral, strike-slip faults. The interior of the Pilar Sur Area is divided into multiple structural compartments by 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 Pilar Sur Area is primarily controlled by the original tide-dominated depositional environment. Depositional axes in many submembers, defined as parasequences 50 to 150 ft (15.2 to 45.7 m) thick, commonly occur as narrow (<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 Pilar Sur Area are documented by a variety of different methods, including identifying unperforated pay from petrophysical analysis, observing anomalies on maps of RMS amplitudes from 3-D seismic data, and delineating abrupt changes in values of water cut and reservoir pressure across faults.

Integrated reservoir characterization has been completed for the northern one-third (VLA-8 Area) of the Pilar Sur Area. The sandstone-body reservoir architecture was delineated in a series of gross-sandstone and log-facies maps annotated by distribution of perforated wells. Locations of newly proposed infill wells were selected through a rigorous comparison of lithology, water-cut, and oil- and gas-production maps. These locations occur mainly in structurally high areas updip of encroachment from injected water; in areas having high SoPhiH values that have low production from nearby wells; and in areas having low water cut, where reservoirs were inferred to be poorly swept.

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

Edgar H. Guevara, principal investigator; Khaled Fouad, Malcolm P. R. Light, Robert E. Barba, Jr., Stephen E. Laubach, and Lisa E. Remington; assisted by Manuel A. Díaz

Mara Este field is one of several giant oil fields in the northwest part of the Maracaibo Basin, Venezuela. Studies of this field are being conducted for Fundación Laboratorio de Servicios Técnicos Petroleros of La Universidad del Zulia, Maracaibo, with funding from Petróleos de Venezuela, S.A., Exploración y Produción. The field produces from structurally complex, naturally

fractured crystalline basement, naturally fractured Cretaceous carbonates, and Paleocene–Eocene terrigenous clastic reservoirs. The study focuses on the east part of the field, referred to as Mara Liviano because it produces mostly light oil. The data base comprises a 3-D seismic survey; wireline log, engineering, and production data from 144 wells; and representative cores and core data. The project's 3-month Phase I comprised collection, quality control, and initial assessment of the data. Phase II of the project is a 16-month reservoir characterization study, whose main objective is definition of field-development strategies for improving production and reserve growth in this mature field.

Production Optimization Modeling, Maraven VLA-6/9/21 Area

Mark H. Holtz, principal investigator;
William A. Ambrose, Joseph S. Yeh, Ramón H. Treviño III, Hongliu Zeng, and Janaka B. Paulis;
assisted by Christi G. Nutter, Ke Sheng Chan, and Chun-Yen Chang

The objective of this 8-month project, funded by Petróleos de Venezuela, S.A., Exploración y Produción, is to test scenarios for maximizing secondary oil recovery in Eocene reservoirs in a structurally and stratigraphically complex field in north-central Lake Maracaibo, Venezuela, through reservoir simulation. The study area, which contains approximately 60 wells, is a production-optimization field laboratory in which new production strategies will be deployed to increase oil recovery. The simulation model incorporates depositional facies and interrelationships among rock-fluid properties. The use of high-resolution, 3-D seismic stratal slicing is a key component in the study, through which the relationship between petrophysical properties and seismic attributes is being determined. The results are also being compared to log-derived gross sandstone and depositional facies models, aiding in the integration of seismic and log data into a full 3-D model.

Analysis of production data includes a full fluid-flow trend study of completion and recompletion results, production logging, injection volumes, pressures, and well-production histories. The analysis demonstrates the effect of facies and faults on well-production character and the spatial residency of remaining hydrocarbons. Three-dimensional geocellular modeling also depicts the reservoir architecture, petrophysical properties, and saturation distribution. This detailed model is being upgraded and applied in a nonequilibrium, initialized reservoir simulation. This simulation is testing the effects of targeted infill wells, production commingling, and varying injection patterns. Preliminary results indicate that a fault-constrained, line-drive waterflood should yield the highest oil recovery.

Sequence Stratigraphic Analysis and Depositional Systems Characterization, Sanvi-Guere Unit, Eastern Venezuela

Douglas S. Hamilton, principal investigator;
Robert E. Barba, Jr., Khaled Fouad, Eric von Lunen, and Michael V. DeAngelo;
assisted by Dallas B. Dunlap and Sunday K. Shepherd

In 1998, the Bureau of Economic Geology, in conjunction with Teikoku Oil de Sanvi-Guere, undertook a detailed sequence stratigraphic analysis and depositional-systems characterization of Tertiary reservoirs in the Sanvi-Guere Unit in Eastern Venezuela. The objectives of the study were to define seismic and structural framework, depositional systems tracts, and hydrocarbon potential of the Miocene Oficina and Oligocene Merecure reservoirs in the Sanvi-Guere Unit, leading to exploration-drilling prospects.

The data base available for study included 520 line kilometers of 2-D seismic, 70 well bores, and production information from existing fields, as well as a 3-D seismic volume in the south part of the unit. We established a sequence stratigraphic framework utilizing the well-bore information and seismic lines. Mapping of the depositional systems and facies variability was undertaken primarily from the well control, but seismic attributes and inversion analysis from the 2-D seismic data were

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The modern Niger River is an analog to braided bed-load and lacustrine facies of the Oligocene Merecure Formation, Eastern Venezuela Basin, Venezuela.

integrated in the mapping process. The structural framework was defined by the 2-D seismic data and refined by projection of structural trends from the 3-D seismic volume in the south part of the unit. Production information was then integrated into the geological and structural framework. The principal hydrocarbon trapping mechanism throughout the unit is a combination of stratigraphic pinch-out and fault seal, which emphasizes the importance of the stratigraphic analysis to successful exploration.

Depositional setting of the Oficina and Merecure reservoirs varies from bed-load and mixed-load fluvial to wave-dominated delta and barrier-strandplain systems. Sediment transport directions during deposition were principally south to north. Subsequent structural tilting was down to the northeast, giving rise to potential combination stratigraphic–structural traps, where reservoir facies pinch out to the west and southwest. Fourteen locations where reservoir facies and structure combine were identified by the joint study and then ranked to provide a drilling portfolio for Teikoku's exploration through 1999.

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

Douglas S. Hamilton, principal investigator; Robert E. Barba, Jr., Khaled Fouad, Mark H. Holtz, Shirley P. Dutton, and Eric von Lunen; Gladys Zannin and Edgar Espinele (Lagoven, S.A.); assisted by Cem O. Kilic and Sandra P. Parra

In 1998, the Bureau, in conjunction with Petróleos de Venezuela, S.A., continued the 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 was to formulate a robust integrated geologic model of the Tertiary and Cretaceous reservoirs and prospects by using the existing geophysical (3-D seismic), geological, petrophysical, and reservoir engineering data base. A detailed analysis of the structural and stratigraphic components of the reservoir framework was conducted, and the location of remaining oil reserves was identified and quantified. The 16-month South Lake project was divided into two phases. Phase 1 was a 10-month geological reservoir characterization study, and Phase 2 was 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 were undertaken 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 the depocenters and depositional systems tracts.

The high-resolution sequence stratigraphic framework constructed for Blocks B, C, and E provided detailed segregation of the complex vertical and lateral assemblages of the carbonate and sandstone reservoirs, leading to identification of several infill and stepout drilling locations in Blocks B and C. The analysis of Block E, as well as the simulation phase of the study, continues through the spring of 1999.

Geologic Analysis of the Mosquitia and Tela Basins, Honduras

Jay A. Raney, principal investigator; Luis A. Sánchez-Barreda and Robin C. Nava

The geologic analysis of the Mosquitia and Tela Basins, Honduras, is a preliminary study to evaluate the depositional systems of sediments of these two offshore basins and adjacent onshore areas. These studies are funded by JGI, Incorporated. The objectives are to prepare a bibliography of available reports and to synthesize available information relevant to the depositional histories and facies distributions within these basins. We will describe the basins using regional seismic data and well logs acquired during previous exploration programs. These offshore data will be combined with published information and onshore geologic data to describe the general facies distribution and structural framework. This study is part of the Bureau's long-term interest in sedimentary basins of Latin America.

Calculation of Permeability and Rock Fabrics from Wireline Logs in the Haradh Area of the Ghawar Field, Saudi Arabia

F. Jerry Lucia, principal investigator; C. Robertson Handford; assisted by Patrick J. Mickler

A key to making accurate performance predictions using flow simulators is to capture the spatial distribution of high and low permeability. An important step in this process is to calculate accurate permeability profiles at each well bore in the reservoir. Because each petrophysical rock fabric has a unique porosity–permeability transform, a single transform cannot be used if more than one petrophysical rock fabric is found in the well bore. The productive Arab-D Formation at Ghawar field contains multiple rock fabrics, and the objective of this project, funded by Aramco Service Company, is to develop a method for identifying the petrophysically significant rock fabrics, characterize their petrophysical properties, and calibrate the fabric and petrophysical properties to wireline log response for the purpose of making accurate estimates of permeability from wireline logs.

The fundamental rock fabrics that can be related to petrophysical properties are grain size, sorting, interparticle porosity, and separate-vug porosity. Permeability and capillary properties improve as grain size and sorting increase. The decrease in interparticle porosity within a grain-size and sorting field decreases permeability and capillary properties. Separate-vug porosity provides reservoir storage but does not add to permeability and tends to trap oil, making oil recovery low. The basic wireline logs that are used to identify these fabrics are neutron, density, acoustic, and resistivity or induction logs. Rock fabrics can be identified by cross plots of water saturation and porosity, with grainstone having lower water saturation than wackestone given the same interparticle porosity. Separate-vug porosity can be estimated from cross plots of traveltime from acoustic logs and porosity from porosity logs. Although these fundamental relationships have been shown to exist, the problem is to calibrate the fabrics and petrophysical properties observed in core material from specific fields by means of wireline logs.

Researchers tested the permeability and rock-fabric algorithms developed during the previous contract, integrated a reservoir-height term into the algorithms, and calculated permeability and rock fabrics from a number of uncored wells. Four cored wells will be used to test the algorithms, and the results will be compared with core analysis and thin-section descriptions. Two cored wells in a structurally low area will be used to determine the effect of reservoir height on the permeability algorithms. Permeability and rock fabrics will be calculated in 14 wells by using wireline logs.

Land, Water, and Environmental Resource Investigations

Environmental, Geologic, and Hydrogeologic Studies

Geo-Environmental Characterization of the Delta del Orinoco, Venezuela

Noel Tyler, principal investigator; Jay A. Raney, Edgar H. Guevara, Robert A. Morton, William A. White, Andres Aslan, John R. Andrews, James C. Gibeaut, Susan D. Hovorka, R. P. Major, Robin C. Nava, and Thomas A. Tremblay; Melba M. Crawford and Solar S. Smith (Center for Space Research, The University of Texas at Austin); assisted by Janize M. Guzman

This project is funded by Petróleos de Venezuela, S.A. (PDVSA), under the direction of the Coordinación del Desarrollo Armónico de Oriente (DAO). Studies to characterize the modern Orinoco delta in eastern Venezuela are part of PDVSA's program to encourage responsible development of this environmentally sensitive region. 1998 was the first full year of studies of the delta, which were initiated late in 1997. The objectives of the Bureau's work are to describe active geologic processes, the geologic framework, and the land cover of this fragile and nearly pristine environment. The Bureau will also develop a data base of environmental baseline data from both our own studies and those of collaborators in Venezuela and will work with DAO in the overall coordination of these activities. During the course of this 5-year project, a digital atlas of the delta, including a multiattribute GIS data base, will be developed that will benefit all who are concerned about the natural resources and sustainable development of this region.

Our first year of study included compilation of existing information; acquisition and processing of satellite imagery (Landsat, Radarsat, JERS); preliminary mapping of land-cover units, which

reflect the interplay of geologic environments of deposition with the distribution of plant communities; initial evaluation of active processes; and development of a preliminary explanation for the geomorphology and depositional systems that reflect the Holocene evolution of the delta. Satellite imagery serves both as base maps and as the primary data sets for mapping and analysis of the delta. The UT Center for Space Research is working closely with Bureau scientists in imagery acquisition and processing. Several extended reconnaissance trips to the delta, resulting in significant new data, are the basis for more detailed studies to be conducted in the coming years.

Initial studies indicate that the upper and lower delta plains of the Orinoco can be differentiated on the basis of land elevation, frequency of flooding, depth to ground water, sediment type, salinity, vegetation, and land use. The lower delta plain is frequently inundated by astronomical tides, fluvial discharge, or rainfall. The ground water is saline to brackish, the water table is shallow, the surface is densely vegetated, and surficial sediments are generally organic rich. In the lower delta plain, dwellings are elevated on poles and indigenous people are mostly hunter–gatherers. In contrast, the surface of the upper delta plain is higher and less frequently inundated. The ground water is brackish to fresh, the water table is deeper, and surficial sediments are weathered muds and sands.

Diverse landforms and processes characterize the lower delta plain, which is subdivided into three regions. The northwest region is dominated by fluvial–tidal interactions, coastal erosion, and human modifications. Dam construction near the head of Caño Mánamo, a large distributary channel, has greatly reduced annual discharge and has led to local channel infilling. On the Atlantic shore east of Caño Mánamo, rapid shoreline retreat has exhumed upper Holocene salt-marsh peat.

The Atlantic shore of the central third of the delta is prograding. Mud capes and sandy spits are forming in response to sediment supplied by large distributary channels and northwesterly directed longshore currents. The currents transport large volumes of suspended sediment from the Orinoco, Amazon, and other rivers and deflect the channel courses of large Orinoco distributaries to the northwest.

The southeast third of the delta is dominated by flow of the main channel of the Orinoco River and the Rio Grande and by semidiurnal tidal processes. This interaction produces an anastomosing

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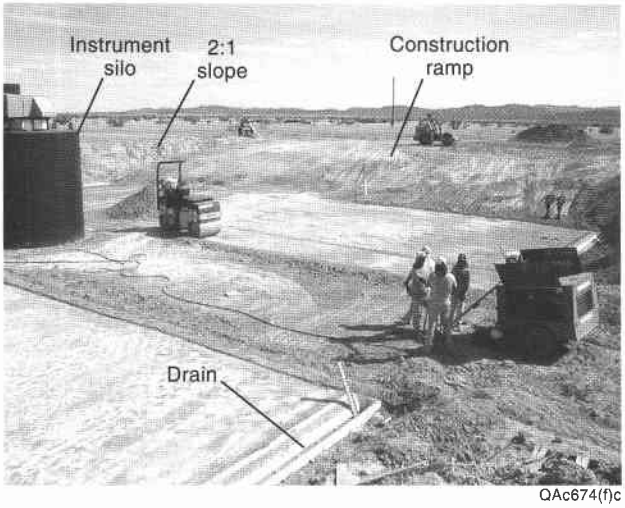
1997 Landsat TM image showing the apex of the Orinoco Delta and its complex array of east-flowing trunk channels, north-flowing distributaries, and flood-basin lakes. The delta apex is bordered by Pleistocene uplands to the north and the Precambrian Guyana Shield to the south.

channel pattern of bifurcating distributaries and intervening islands that are stabilized by mangrove forests. Longshore transport is negligible because the Guyana headland shelters this part of the delta from longshore currents that flow across the subaqueous delta platform. Geomorphic evidence indicates that the Rio Grande, the main channel of the Orinoco River, has remained confined to the south part of the delta during the Holocene, whereas distributary channels of the northern delta have avulsed frequently.

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, Jinhuo Liang, Robert E. Mace, and Robert C. Reedy; assisted by Wan Joo Choi

Bureau studies to support the State of Texas in developing a site for the safe disposal of low-level



Engineered barriers constructed in the summer of 1997 in the Chihuahuan Desert of Hudspeth County, West Texas, for the Texas Low-Level Radioactive Waste Disposal Authority include a capillary barrier and an asphalt barrier. The Bureau was responsible for instrumenting these barriers to monitor water balance. Monitoring data are being used in numerical simulations to assess the performance of the different engineered-barrier designs.

radioactive wastes continued in 1998. This work is funded by the Texas Low-Level Radioactive Waste Disposal Authority and the U.S. Department of Energy. The Bureau conducted additional technical studies and provided expert testimony to the State.

The technical studies consisted mainly of monitoring prototype engineered covers that were installed in 1997. The various components of the water balance are being monitored to evaluate the performance of two different designs of engineered barriers: an asphalt barrier at a depth of 4.3 ft (1.3 m) and a capillary barrier at a depth of 6 ft (2.0 m). Precipitation, surface runoff, subsurface runoff along the top of the asphalt, and deep drainage are being monitored. In addition, horizontal and vertical neutron-probe access tubes and time-domain reflectometry probes were installed to monitor water content, and thermocouple psychrometers and heat-dissipation sensors were installed to monitor potential energy. A total of several hundred instruments are being monitored daily. The engineered covers were vegetated in the summer of 1998, and, using an irrigation system, we applied water to the plants over several weeks. A special session was convened at the American Geophysical Union to evaluate issues related to the installation, monitoring, and modeling of engineered covers over waste-disposal facilities. Monitoring of the natural system is ongoing and includes water potential and neutron-probe logging near Fort Hancock and Eagle Flat. The data sets developed from these monitoring programs are unique and show that in interdrainage areas infiltration of water is minimal.

Spatial and Temporal Variability of MTBE Plumes in Texas

Robert E. Mace and Alan R. Dutton, principal investigators; assisted by Wan-Joo Choi

Methyl tert-butyl ether [MTBE, $(CH_3)_3C(OCH_3)$] leaked from petroleum storage tanks, such as those at gasoline stations, is an environmental concern in Texas and in other states. MTBE is a synthetic solvent that has been added to gasoline since 1979, when it was approved as a blending component by the U.S. Environmental Protection Agency (EPA). Originally intended to increase the octane of gasoline, MTBE has been used since the early 1990's as an oxygenate, which is a substance that raises the oxygen content of gasoline to promote greater combustion efficiency and lower carbon monoxide emissions. MTBE contamination of ground water has become an environmental concern owing to its appearance in urban and municipal water wells. In Texas, MTBE has been detected in shallow urban wells and in at least seven water-supply systems and one private drinking-water well. The primary source of ground-water contamination by MTBE is leaking petroleum storage tanks predominately beneath gasoline stations.

The objective of this project was to estimate the size of MTBE plumes in Texas and how they change over time. Using a data base consisting of 609 sites, we summarized maximum site concentrations and estimated MTBE plume lengths at 99 LPST sites and benzene plume lengths at 289 LPST sites. We found that MTBE is detected in shallow ground water beneath 93 percent of LPST sites in most parts of the state. Most sites (85 percent) have maximum MTBE concentrations that exceed the lower limit of the EPA advisory level (20 parts per billion [ppb]), and many sites (60 percent) have maximum MTBE concentrations that exceed the protective concentration level proposed for Texas (730 ppb). Geometric mean plume length for MTBE at a concentration of 10 ppb is 182 ft. MTBE plumes are, on average, about 27 ft longer than benzene plumes and are longer than their companion benzene plumes at 56 percent of the sites. Our results show that 83 percent of wells have stable, decreasing, or no MTBE concentration and constant co-occurrence of MTBE with benzene. Moreover, examples of stable MTBE plumes suggest that many MTBE plumes in Texas

may be naturally attenuated. This conclusion of natural attenuation, however, is preliminary. Better site-specific temporal data are needed to confirm the occurrence of natural attenuation of MTBE and to estimate the fraction of sites that have stable, growing, or receding plumes.

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

Robert E. Mace, principal investigator; Alan R. Dutton and John R. Andrews

The objective of this project is to provide the Texas Water Development Board with an interactive, user-friendly, and updatable data base on permeability and storativity of the Carrizo–Wilcox aquifer. Permeability (transmissivity and hydraulic conductivity) and storativity data are needed to address a host of regional ground-water management issues as part of long-term regional water plans involving the Carrizo–Wilcox aquifer. State-mandated programs call for the development of regional water plans that address near- and long-term water needs that consider surface- and ground-water resources. Those responsible for developing regional water plans require permeability and storativity data to make accurate predictions of the viability of ground-water resources in the future.

Our approach is to compile, evaluate, synthesize, and geographically reference available permeability and storativity data on the Carrizo–Wilcox aquifer. Compilation includes publicly available published and unpublished data from local, regional, State, and Federal agencies. We will evaluate pumping-test data to estimate transmissivity, hydraulic conductivity, and storativity. We will evaluate transmissivity from specific capacity using analytical and aquifer-specific empirical techniques. We will synthesize permeability data by statistically summarizing results, defining the spatial continuity, and relating permeability and storativity data to geologic and hydrologic setting. All results will be georeferenced in a geographical information system and published as a final report and CD-ROM.

Evaluation of Interplaya Recharge on the Southern High Plains

Bridget R. Scanlon, principal investigator; Edward S. Angle and Robert C. Reedy

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. We drilled two boreholes (21.2 and 23.0 m deep) and collected soil samples in order to analyze water content, water potential, chloride, and stable isotopes of oxygen and hydrogen. The soil physics and environmental tracer data are consistent with higher water fluxes near the surface as a result of infiltration and much lower water fluxes below the wetting front. Estimated water fluxes ranged from 0.1 to 2.5 mm yr^{-1}. These results resemble previous findings on water fluxes in interplaya settings near the Pantex Plant. Instrumentation for monitoring infiltration includes thermocouple psychrometers to measure water potential and temperature, heat-dissipation sensors to measure matric potential, and time-domain reflectometry to measure water content. Thermocouple psychrometers were installed in the two boreholes in a retrievable manner and in a shallow pit, whereas the heat-dissipation sensors and time-domain reflectometry probes were installed only in the pit. Water content, water potential, and temperature are logged daily and compared with rainfall records to evaluate infiltration. Estimates of infiltration in interplaya settings will be an important component of a sitewide environmental-impact statement that will be required of any new missions at the Pantex Plant. This work is being funded by the U.S. Department of Energy.

Monitoring Techniques Related to Subsurface Gas Transport

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

The purpose of this study is to evaluate different techniques of estimating gas transport parameters and of monitoring subsurface gas migration. The work, conducted at the Maricopa Agricultural Center in collaboration with the University of Arizona, is funded by the U.S. Nuclear Regulatory Agency. Subsurface pressure variations in response to barometric pressure fluctuations were monitored, and the response of the subsurface to diurnal and longer term variations in atmospheric pressure was recorded. From the resulting data, minimum vertical air permeabilities were calculated. Results of this monitoring can be used to optimize sampling of gases transported by atmospheric pumping. In addition, pneumatic pressure tests were used to measure vertical and horizontal air permeabilities at different depths. Air was injected in a central well, and pneumatic pressure was recorded in monitoring wells. Pumping tests were conducted at different injection and extraction rates. We evaluated the data using analytical solutions for steady-state gas flow. Results from the pneumatic tests agreed with those

from barometric pumping and showed high permeabilities in this gravely, sandy material. The results of this study provided valuable information on methodologies for measuring gas-transport parameters required for simulation of volatile contamination migration and for performance assessment.

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

Bridget R. Scanlon, principal investigator

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 toward Homer Wash. A National Academy of Sciences panel made several recommendations to evaluate recharge at this site, and the study is being conducted to address these recommendations. A test plan was developed that outlines the response to each of the recommendations, and which was reviewed by the Nuclear Regulatory Commission and faculty from various California universities. Planning meetings were held in California to outline drilling techniques and protocols and sampling schemes. Soil physics and environmental tracer data will be collected from boreholes ranging in depth from 30 to 213 m (depth to water table). This project is funded under a contract with the Program Management Company for the California Department of Health Services.

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

Jay A. Raney, principal investigator;
E. Jeri Sullivan and Thomas A. Tremblay;
assisted by Maria Bondarenko and Wan-Joo Choi

The Texas–Mexico border area is undergoing rapid development associated with NAFTA. An improved data base of geologic and other natural-resource and environmental information is needed to support responsible development and wise decision making. We are now completing the first year of a 2-year study funded by the Texas Higher Education Coordinating Board that will both improve data availability and train new professionals in digital mapping and analysis. The project is led by the Bureau but includes major components of work that are being accomplished by the universities of the border area: The University of Texas at Brownsville, The University of Texas Pan American at Edinburg, The University of Texas at El Paso (UTEP), and Texas A&M International University at Laredo.

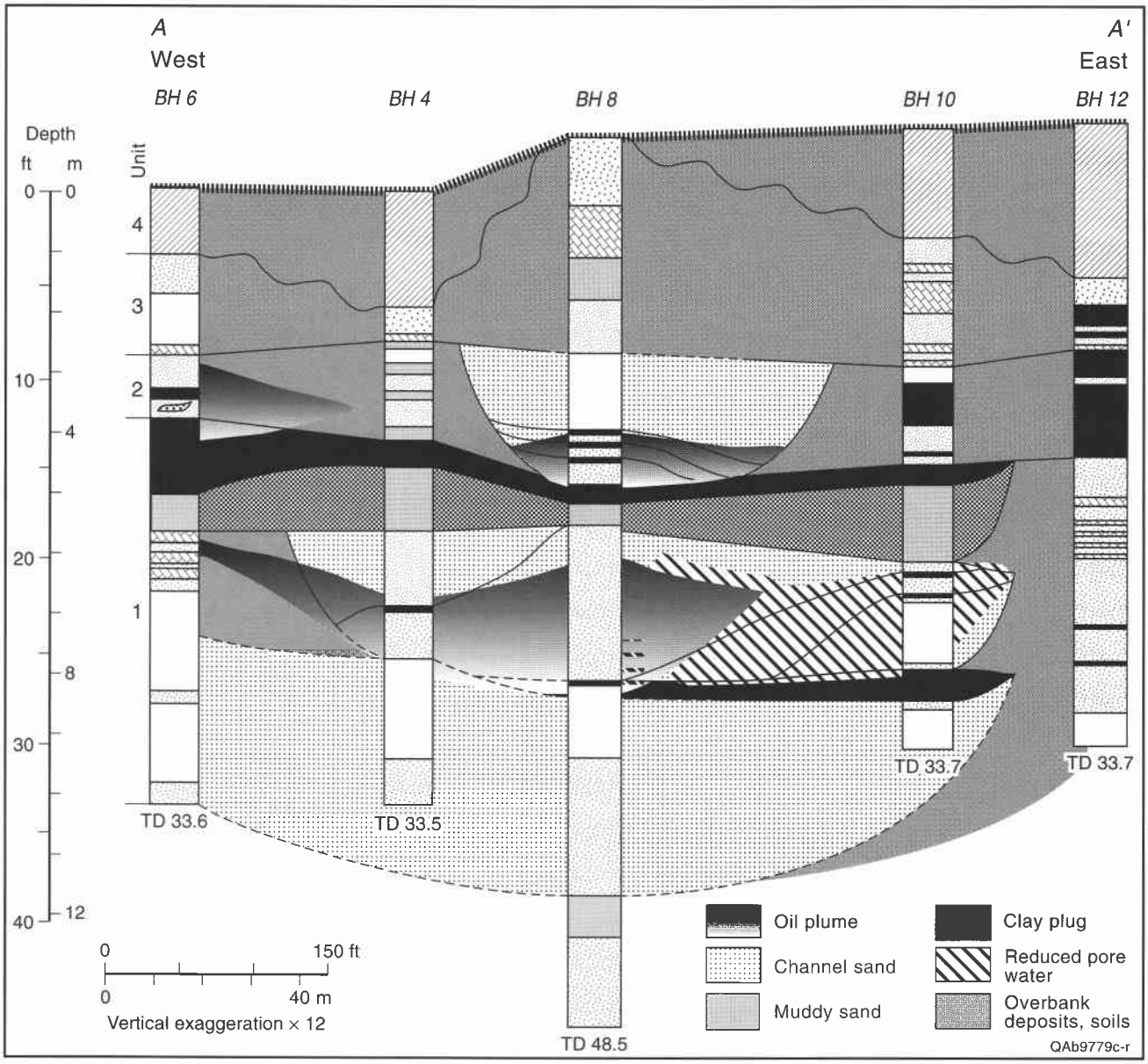
Existing geologic maps of the border region are being entered into a geographic information system (GIS). Mexican geologic maps of the border area were divided among the schools, and digitizing is progressing quickly. These will provide a common base for additional research associated with this project and will provide students at the participating schools with practical geographic and geologic skills. Research topics that are proposed to follow from the digitizing process include urban change, surface- and ground-water hydrology, geologic mapping for map verification, and studies of agriculture and land use.

Digitizing of the adjacent Texas geologic maps is proceeding rapidly at the Bureau. The Bureau will next begin to integrate the Mexican and Texas digital maps into seamless data sets. UTEP is assisting with locating and distributing satellite imagery and other remotely sensed data. A training course in GIS software (ArcView), remote sensing, and image processing was held at UTEP for students and project personnel. Coordination meetings are held on the various campuses of the participating universities. A tour of the Borderlands Information Center, which may assist in the distribution of the final data sets, was included as part of the Austin coordination meeting.

Analysis of Texas Oil-Field Eligibility for Variance from Area-of-Review (AOR) Requirements

Alan R. Dutton, principal investigator; Rebecca C. Smyth, Robert E. Mace, Robin C. Nava, and E. Jeri Sullivan; assisted by Wan-Joo Choi, Benjamin P. Elliott, and Susan Palachek

Underground Injection Control (UIC) regulations of the Railroad Commission of Texas (RRC) require an applicant for an injection well to perform an area of review (AOR) study within a 0.25-mi radius of the proposed injection well. The purpose of an AOR study is to identify wells that might allow injected fluids to migrate upward from the injection zone and endanger underground sources of drinking water. The RRC adopted rules that allow an applicant to apply for a variance to the 0.25-mi-radius review for an oil field or other geographic area on the basis of approved factors. During 1998 the Bureau worked with the RRC to evaluate oil fields in Texas that might qualify for a variance from the AOR-permitting requirement on the basis of reservoir-pressure relationships, one of the approved variance methods. The work



West-east cross section of an abandoned oil-field site in Sinton, Texas, that is seeping oil to a local creek. Bureau environmental geoscientists determined that the distribution of oil and dissolved organic compounds leaked from an oil-field pipeline is controlled by the geometry of fluvial channel-fill deposits in the Pleistocene Lissie Formation.

included developing a methodology for using the RRC's data bases to analyze the vertical separation between fluid level in the reservoir and the base of usable quality drinking water (BUQW) and applying the methodology to identifying which Texas oil fields might readily qualify for the variance. The study was funded by the U.S. Department of Energy and administered under subcontract from BDM–Oklahoma.

An RRC data base contains production-zone fluid-level measurements (Form H-15) for shut-in and abandoned wells in more than 8,100 oil fields in Texas. On the basis of discussions with the Texas Oil and Gas Forum, the RRC and the Bureau have decided to focus the analysis on fields that are currently receiving injection-well permitting requests, that have an appreciable number of injection wells, and that have an average production-zone fluid level significantly deeper than the BUQW. A preliminary RRC query of the data base found 1,587 fields satisfying the criteria, containing 36,284 permitted injection wells.

Further queries identified approximately 113 oil fields having data sufficient for the AOR variance analysis. The Bureau first evaluated these oil fields on the basis of statistical graphs of H-15 fluid level and BUQW data. We then used statistical and GIS methods to study in detail the

60 fields that were found to possibly qualify for a variance recommendation. We found that five fields (Adair [Wolfcamp], Hitts Lake [Paluxy], Joy [Strawn], Panhandle [Red Cave], and Vealmoor) can be recommended, for the AOR variance with existing information. In addition, 16 oil fields would most likely qualify for a variance recommendation, and 21 might qualify for a variance if more production-zone fluid-level data were provided to the RRC. Preliminary results of this study were presented at RRC-sponsored technology-transfer workshops held in Midland and Dallas. Additional workshops are planned after the report is finalized.

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

Alan R. Dutton, principal investigator; Susan D. Hovorka, Robin C. Nava, Jeffrey G. Paine, Rebecca C. Smyth, and E. Jeri 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. Since 1995 the Bureau has assisted the RRC in evaluating sites where previous investigations were unable to define the source of contamination, where the subsurface extent of the contaminant is unknown, or where complex subsurface geology affects remediation feasibility. Our investigations have focused on finding cost-effective remedial solutions and limiting costs by applying nonintrusive and state-of-the-art hydrogeological models and investigation techniques.

Work during 1998 included a 4-month assessment of one site in West Texas and the completion of studies and reports begun in 1997 at eight other sites across Texas. The constituents of concern at these diverse sites include saltwater, spent drilling fluids, crude oil, and natural gas.

We began, in late 1998, a phased assessment of one oil-field site in Howard County that has saltwater seeping into an intermittent tributary of Beals Creek, approximately 20 mi upstream of its confluence with the Colorado River. The main Phase-1 objectives were to delineate and characterize the extent of saline ground water at the site and constrain possible source areas. Field work included (1) constructing monitoring wells; (2) sampling and analyzing water from monitoring wells, water wells, and seeps; (3) trenching and describing tributary alluvium; (4) surveying sample points; (5) employing borehole geophysical logging; and (6) building reconnaissance geophysical transects between wells.

Optimal Geological Environments for Carbon Dioxide Disposal in Saline Aquifers in the United States

Susan D. Hovorka, principal investigator

Saline aquifers have been widely recognized as having high potential for long-term (geologic time scale) sequestration of greenhouse gases, particularly CO_2, as a mechanism for decreasing the impact of burning fossil fuel on global warming. This study, funded by the U.S. Department of Energy, is designed to fill the gap between studies using idealized aquifers and the complex and often poorly known properties of real saline aquifers.

We are using reservoir-characterization and geologic-play approaches to extend our knowledge from well-known areas (saline aquifers closely associated with hydrocarbon production) to poorly known areas (potentially large volume, unproductive saline-aquifer targets for sequestration) by means of conceptual geologic and hydrologic models. Although reservoir-characterization and play approaches are standard techniques for hydrocarbon exploration and development, they require innovative modification to determine what hydrogeologic settings are best for CO_2 injection. During Phase I of the project, we are developing hydrogeologic screening criteria for identifying optimal saline aquifers for CO_2 sequestration in three to five subregional areas.

Characterization of Bedded Salt for Storage Caverns—Case Study from the Midland Basin

Susan D. Hovorka, principal investigator

Bedded salt is a geologic resource used internationally to host solution-mined underground storage facilities. Storage caverns are used by the chemical and petrochemical industry for storing product and chemical feedstock and for extracting brine used by drilling and chemical industries. Three salt caverns have been licensed for sub-

surface disposal of oil-production waste in the Midland Basin.

This study, funded by the U.S. Department of Energy, provides a regional description of bedded salt in the Midland Basin, a template for useful and geologically based description of salt in other basins worldwide, and recommendations about the approaches for site-specific investigations. Geologically based interpretation of depositional facies and postdepositional modification by salt dissolution provide a powerful tool for mapping the geometry of salt in order to assess the suitability of sites for developing solution-mined storage caverns.

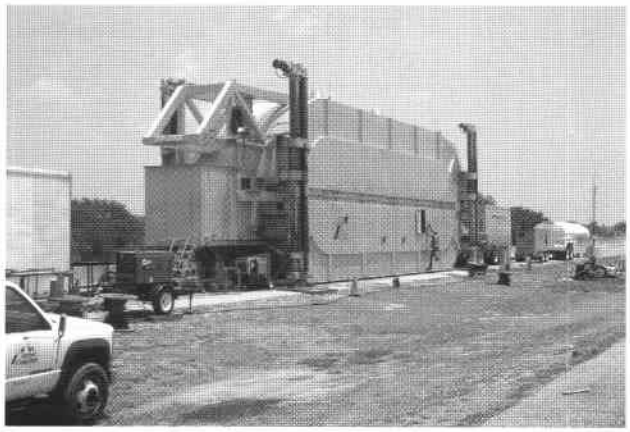
The thickest and most extensive salt (Salado Formation) shows a strong and consistent regional thickening toward the southwest across the Central Basin Platform toward the Delaware Basin. Toward the upper part of the Salado Formation, salt beds vary in thickness, become discontinuous in lateral extent, and pinch out toward the Midland Basin margins. This geometry is interpreted as the result of complex depositional patterns that developed toward the end of basin filling, as well as salt dissolution beneath the sequence boundaries preceding and following Alibates deposition. Salt beds have thinned and dissolved toward the east structural margin of the Midland Basin, where salt is near the surface as a result of ongoing postdepositional dissolution.

Local salt dissolution is noted in three areas. Salt beds have dissolved over the structural high at the south end of the Central Basin Platform and on the south side of the Howard–Glasscock high. A coincidence is observed between the southern Central Basin Platform structural high and the modern Pecos valley; this relationship is attributed to localization of drainage in depressions caused by enhanced salt dissolution where salt is at a shallow depth. This is a self-reinforcing process. The third area of focused dissolution overlies the Capitan reef, rimming the Delaware Basin. In this area, dissolution has occurred both from the top and the bottom of the salt.

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 by using available soil and geologic data, along with rapid geophysical tests. Depth-to-bedrock estimates, which are necessary for assessing pavement condition, are currently based on analysis of falling weight deflectometer data without benefit of the abundance of information available on near-surface soils and rocks. Considerable effort has been expended over the last few decades by earth scientists to produce maps, cross sections, and soil profiles that focus on the upper few meters of the subsurface, a critical zone for roadway design and performance. These data provide a semi-quantitative basis for determining regional and local differences in expected bedrock rigidity and depths to bedrock across Texas. Furthermore, 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.



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Texas Department of Transportation's Mobile Load Simulator, shown operating on U.S. 281 near Jacksboro, Texas, estimates long-term pavement performance by simulating years of road use. Interpretation of these and other highway data require knowledge of bedrock type and depth, which Bureau scientists provide by mapping geologic units and making geophysical measurements. Photo by Jeffrey G. Paine.

In this project, the Bureau and CTR are (1) evaluating the utility of existing soils and geological maps in estimating depth to bedrock; (2) subdividing the state into regions of similar bedrock type; (3) establishing soil- and rock-type variations within a region that allow for the definition of units that have similar physical properties and depth-to-bedrock ranges; (4) developing seismic-refraction guidelines for survey design, acquisition parameters, and data analysis to allow rapid and 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, and optimize acquisition parameters for the refraction survey

on the basis of qualitative depth-to-bedrock estimates from geologic and soil maps.

Ground Investigation of Geophysical Anomalies Detected by Airborne Survey of the Hatchel Area

Jeffrey G. Paine, principal investigator

Bureau researchers recently completed a Railroad Commission of Texas (RRC)-funded project investigating the usefulness of airborne geophysical methods in identifying oil-field salinity sources in the Colorado River watershed. That study demonstrated that the airborne electromagnetic induction method (EM) readily identifies salinized ground and can be used to help discern likely oil-field-related salinization from that arising from natural sources or agricultural activities. Despite the success in identifying salinized ground and quantifying lateral and vertical extent of salinization, challenges remain in determining the type of oil-field salinization from airborne data—is the salinization caused by a leaking well, a surface spill such as a leaking tank battery, or by an inactive brine-disposal pit?

In this follow-up study, Bureau researchers are investigating 35 anomalous sites in the Hatchel airborne-survey area that fit a profile of a well that is potentially leaking saltwater. Ground-based geophysical measurements at each of these sites are being used in an attempt to distinguish wells that are most likely leaking from other oil-field sources and refine the airborne profile of a potentially leaking well. Ultimately sites that meet airborne and ground-based EM criteria will be candidates for plugging by the RRC.

Also under this project, Bureau staff are training RRC field personnel in the use of ground-based EM equipment. At the completion of the project, RRC staff will be able to discern where the use of EM equipment is appropriate, determine lateral extent of salinization, locate potential sources of near-surface salinization, and suggest whether specific wells show evidence of leakage.

Mapping Near-Surface Salinization Using Long-Wavelength AIRSAR

Jeffrey G. Paine, principal investigator

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

We will assess the utility of the radar method by acquiring long-wavelength AIRSAR reflectivity images at two Texas test sites where extensive airborne and ground-based EM surveys have already been conducted. These reflectivity images, which are affected by both the roughness of the surface imaged and the electrical properties of the near-surface materials, may reveal an electrical conductivity signature related to the large increase in ground electrical conductivity that accompanies salinization. The first AIRSAR flights over the test areas are scheduled for late 1998 or early 1999.

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

Jay A. Raney and William A. White, principal investigators; Thomas A. Tremblay; Melba M. Crawford, and Solar S. Smith (Center for Space Research, The University of Texas at Austin)

This project was a follow-up to a previous, nationwide study by the Bureau and Center for Space Research to determine the extent and rates of deforestation in Belize. In this study, a more detailed evaluation of land cover and land use in south-central Belize was conducted in support of efforts by the Government of Belize to develop current land-use maps. Funding was provided by the United Nations Development Programme through the Government of Belize, Ministry of Natural Resources.

Bureau researchers worked closely with the Ministry of Natural Resources technical staff, who provided ground transportation in Belize and accompanied Bureau staff during field surveys. Landsat Thematic Mapper imagery acquired in 1996 was the primary imagery used in the analysis of land cover. The project area was selected because it is relatively cloud free in the 1996 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 was based on our previous experience in Belize and was verified by field studies and a low-altitude aerial survey.

A total of 14 land-cover and land-use units were classified, including broadleaf forest, pine forest, secondary regrowth, savannah, mangrove, marsh–swamp, farmland, and residential–commercial development. To assist in the classification and delineation of map units, more than 120 field sites were examined and precisely located according to a Global Positioning System during field surveys in March and August 1998.

At the conclusion of the study, a workshop that focused on the methodology and results of the study was presented in Belize. Results were also presented in a map of land cover–land use and a technical report prepared for the Ministry of Natural Resources. This study provides the basis for image classification that can be applied elsewhere in Belize.

CO_2 Sequestration in Abandoned Hydrocarbon Reservoirs

Andrew R. Scott and Mark H. Holtz, principal investigators; assisted by Carlos A. Rodney

Emissions of industrial greenhouse gases have increased the total load of carbon in the atmosphere. Although the long-term consequences of these emissions are hotly debated, one possible outcome is the alteration of global climate as greenhouse gases trap heat at the Earth's surface. One possible method of reducing the atmospheric carbon budget is to sequester a key industrial greenhouse gas—carbon dioxide (CO_2)—in subsurface reservoirs. The likelihood that this method of CO_2 disposal will become economically feasible is greatly increased if the disposal process provides readily quantifiable ancillary benefits, such as enhanced oil recovery though CO_2 injection. Whereas the benefits of reducing CO_2 emissions are long term, global, and potentially difficult to quantify, the benefits of enhanced oil recovery are immediate and quantifiable.

The proximity to large power plants of oil and gas reservoirs, many of them nearing their apparent economic limit, makes Texas the logical geographic area to test the feasibility of this method of greenhouse-gas sequestration in the United States. Funded by the Electric Power Research Institute, this preliminary Bureau investigation of the suitability of Texas reservoirs for sequestering CO_2 produced by major power plants consists of two phases. In Phase One of this project, we will review the extensive literature that defines favorable conditions for sequestering CO_2 in hydrocarbon reservoirs. Once we have developed a comprehensive range of geologic and engineering parameters compatible with CO_2 sequestration, we will review data from Texas oil and gas reservoirs that are nearing abandonment and develop a list of ranked prospective CO_2 disposal sites.

Issues associated with injecting CO_2 into hydrocarbon reservoirs include geologic, engineering, and geochemical characterization of the reservoir and proximity of the reservoir to power plants. Although the composition of waste gases from existing power plants is highly variable, for this preliminary study we assumed that the only waste gas injected into the reservoirs is CO_2. The second phase of this project will evaluate key economic factors, such as the proximity of the selected hydrocarbon reservoirs to existing power plants or the compositional variability of waste gases and their effect on sequestration.

Coastal Studies

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

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

The Bureau was the lead agency in this cooperative study with the Texas Parks and Wildlife Department (TPWD) and Texas A&M University at Corpus Christi (TAMU-CC). The project was funded by the U.S. Environmental Protection Agency and the Texas Natural Resource Conservation Commission as part of the Corpus Christi Bay National Estuary Program (CCBNEP).

Major objectives of the study were to (1) determine the status and trends of wetlands, wind-tidal flats, and riparian woodlands; (2) classify and map hardened and natural shorelines; (3) characterize estuarine and palustrine emergent wetlands in terms of their prevalent plant associations; and (4) determine the trends in vegetation cover on natural and dredged-material, rookery islands. These types of data are critical for developing sound and comprehensive management practices for this nationally recognized estuarine system.

The study area (which included Corpus Christi and Aransas Bays and the secondary bays of

Copano, Nueces, Mesquite, and Redfish, upper Laguna Madre, and offshore barrier islands) encompasses an extensive, biologically productive estuarine and lagoonal system composed of numerous diverse and essential habitats.

Status and trends of wetlands were determined by geographic information systems analysis of U.S. Fish and Wildlife Service (USFWS) National Wetlands Inventory (NWI) maps interpreted from 1950's, 1979, and 1992 aerial photographs. Hardened and natural shorelines were mapped from high-quality, 1997 low-altitude aerial videotape surveys. Aerial photographs and USFWS NWI maps were the primary sources of information for analysis of riparian woodlands. Prevalent wetland-plant associations and rookery-island vegetation were characterized from field surveys, maps, aerial photographs, and existing reports.

Among the findings of the study were 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, there have been net gains in both of these resources. Gains in salt marsh are partly the result of rising sea levels that flooded tidal flats and contributed to the spread of marshes dominated by *Spartina alterniflora* in intertidal areas. In permanently flooded areas, seagrass beds expanded. Correspondingly, a reduction in the total area of tidal flats has occurred since the 1950's. Results of the study have provided information on the health of the bay system and will be incorporated into the CCBNEP comprehensive conservation management plan.

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

William A. White and Robert A. Morton, principal investigators;
Thomas R. Calnan (Texas General Land Office)

The major objectives of this investigation were to inventory and evaluate marsh restoration and creation projects in the Galveston–Trinity Bay System. The study was conducted in cooperation with the Texas General Land Office (TGLO) and was funded by TGLO and the U.S. Environmental Protection Agency (EPA).

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. Large-scale restoration of wetlands will help the State of Texas achieve the goal of no overall net loss of State-owned wetlands. In addition, the Galveston Bay Plan considers wetlands loss and degradation as the number-one management problem for the Galveston–Trinity Bay system, and, therefore, gives a high priority to increasing the quality and quantity of wetlands, setting as a goal the 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 were the evaluation and synthesis of primary physical criteria for large-scale marsh creation.

Detailed field surveys were used to inventory and evaluate wetland restoration, enhancement, and creation projects in terms of their original design criteria, objectives, physical characteristics, geomorphology, hydrology, site stability, vegetation, success in meeting performance goals, and potential for large-scale application. Data were collected at seven marsh restoration–creation sites located around the Galveston Bay system. The study sites include former upland areas that were scraped and graded and subtidal areas that were filled with dredged material to achieve intertidal elevations. Vegetation planted at the sites were primarily cordgrasses, *Spartina alterniflora* and *Spartina patens.*

Of the seven sites analyzed, two were primarily fill sites, two were fill and shape sites, two were scrape-down sites, and one was a natural substrate with shore protection. Fill sites in general achieved a higher density of vegetation over a shorter period of time, partly because of relatively flat intertidal surfaces. At scrape-down sites, however, more precise and intricate geomorphic and hydrologic features in aquatic and marsh habitats could be developed. Both scrape-down and fill sites, as well as combinations of the two, have potential for large-scale development. Because scrape-down sites are usually developed in uplands, they have the potential of adding wetlands without displacing aquatic (bay-bottom) habitats and, thus, expanding the overall area of wetland habitats in a bay system. In fill sites, vast quantities of dredged material from navigation channels provide a potential source of fill for large-scale development. Most of these sites displace bay-bottom habitats, but in many cases in the Galveston Bay system, the sites are former marshlands that have been lost to subsidence. In currently subsiding zones, acquisition of adjacent transitional areas and uplands can provide an elevated substrate for the growth and expansion of wetlands in response to relative sea-level rise. The criteria and techniques identified

for large-scale marsh development in the Galveston–Trinity Bay system have potential for application in other bay-estuary-lagoon systems.

Integrity of Houston Ship Channel Archeological Sites

Jeffrey G. Paine, principal investigator

This joint project with 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 have remained intact. Galveston Bay is one of the most altered and rapidly changing coastal areas in the United States. Natural inundation caused by relative sea-level rise, extensive dredging and disposal activities, hydrocarbon exploration and production, and ground-water withdrawal have all 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 the likelihood of reported sites being intact, submerged by rising sea level, eroded as shorelines have retreated, covered by subsequent dredge material, or reworked remnants of material dredged from nearby ship channels. Such an analysis allows archeologists to focus labor-intensive excavation efforts 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 in order 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 that the earliest maps were made to the date of the most recent aerial photographs.

Mapping Barrier Islands Using Airborne Synthetic Aperture Radar (AIRSAR)

James C. Gibeaut and Melba M. Crawford (Center for Space Research, The University of Texas at Austin), co-principal investigators; Roberto Gutierrez; assisted by K. Clint Slatton, Amy L. Neuenschwander, and Michael R. Ricard

This 3-year project, which is funded by the National Aeronautics and Space Administration (NASA) and conducted jointly 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, sedimentary environments, and wetland vegetation. The AIRSAR instrument, operated by NASA's Jet Propulsion Laboratory (JPL), is flown in a DC-8 aircraft. The study area lies along the Texas coast between Sabine Pass and Freeport.

The AIRSAR instrument can be operated in a multipolarization, multifrequency mode (POLSAR) or a topographic mapping mode (TOPSAR). The POLSAR data have a ground resolution of 4 to 8 m. Radar energy is transmitted to the ground from the aircraft in vertical and horizontal polarization. The energy interacts with the ground, and a part of it is scattered back to the aircraft and received in vertical and horizontal polarization. The varying wavelengths and polarization interact with the vegetation and substrate differently. The POLSAR mode is sensitive primarily to surface roughness on the scale of the wavelength and to geometry (for example, vertical tree trunks versus branching bushes) and secondarily to electrical properties. The longer wavelength, L- and P-band radar can penetrate vegetation and interact with the substrate.

The TOPSAR mode provides a digital elevation model (DEM) using interferometric techniques. The method is based on the concept that radar signals received by two antennas on the aircraft 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.

In 1995, 1996, and 1998, the project acquired POLSAR and TOPSAR data. In 1996 researchers also obtained Calibrated Airborne Multispectral Scanner (CAMS) data and simultaneous color-infrared photography of Galveston Island and Bolivar Peninsula. Analysis has shown that radar can discriminate among sedimentary environments of barrier-island systems.

Bureau scientists are developing techniques to classify the radar data statistically, focusing on delineating coastal wetland from upland areas and further discriminating the wetland areas into transitional, low- and high-marsh, and barren tidal flats. A hierarchical classification approach shows much promise. Researchers are developing multisensor classification procedures in which optical CAMS data are combined with radar data.

DEM's will also be added to the classification routines, most likely improving the mapping because coastal vegetation types are highly sensitive to small (10-cm) elevation changes. Furthermore, researchers are modeling the radar signatures, which, by providing information on the sensitivity of the radar to certain ground characteristics, aid interpretation and classification of images.

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, which is funded by the Texas Coastal Management Program and the National Aeronautics and Space Administration (NASA), is providing critical information for the monitoring and management of the coastal dune and beach system along the Galveston County shoreline. In 1997 we resurveyed 32 dune and beach topographic transects established in 1994 as part of the Texas Natural Resources Inventory. A comparison of the 1994 and 1997 transects shows that the vegetation line moved landward 10 to 70 ft along the west half of Galveston Island. On Bolivar Peninsula, 10 to 40 ft of retreat occurred in the High Island to Rollover Pass area.

NASA provided funds for an airborne laser-altimeter survey. In November 1997 and August 1998, we surveyed the Galveston Island and Bolivar Peninsula shorelines using an Airborne Laser Terrain Mapping (ALTM) instrument. The Optech ALTM-1020 integrates a pulsed, solid-state laser, an inertial motion unit, and a geodetic GPS receiver to measure variations in ground elevation. We installed the ALTM-1020 in a single-engine Cessna 206 operated by the Texas State Aircraft Pooling Board and mapped more than 163 km^2 in 1 day (40 km^2 per hour), having a laser ground-point spacing of 2 to 6 m. Ground-survey and ALTM data agree to within approximately 15 cm in elevation. Individual houses and trees are clearly discernible in the data, and beaches and dunes are well defined.

The ground and airborne surveys 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 are exploring relationships between processes, physical setting, and dune and beach morphology. This information will aid State and local planners and local residents in their decision making and design of erosion-mitigation projects. To this end, the project will present the data and interpretations in a form accessible to local governments and interested citizens.

Shoreline Change on San José Island between 1974 and 1998

Robert A. Morton, principal investigator; John R. Andrews and James C. Gibeaut

San José Island is one of the few barrier islands on the Texas coast that has not been significantly altered by human activities. As such it serves as a good test site for studying physical processes operating at the shore that cause shoreline movement. Because sand is free to move along the shore of the island, any long-term trend in shoreline movement is likely to be a result of natural changes in sediment supply by longshore currents or changes in relative sea level.

A primary objective of this study was to map the Gulf shoreline on San José Island using Global Positioning System (GPS) techniques and to evaluate shoreline movement since 1974. Another objective was to digitize the previously mapped shoreline positions (1860's to 1974) using a Geographic Information System (GIS) so that future comparisons of shoreline position and calculations of rates of change could be automated and as precise as possible.

Several beach profiles were surveyed at selected sites along San José Island to compare changes in beach morphology since 1974. The information on historical shoreline changes was summarized in four different forms: (1) maps in 1:24,000-scale U.S. Geological Survey format showing the different shoreline positions, (2) tables depicting the distance and rate of change in shoreline position between 1974 and 1998, (3) shoreline history plots illustrating the long-term trend in shoreline movement, and (4) a report that describes the most recent changes in shoreline position and their causes.

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

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

The Texas Coastal Management Program is funding this joint project of The University of Texas, the Texas Department of Public Safety,

and Texas A&M University to develop a Coastal Hazard Atlas of the Galveston Bay and Sabine Lake area. The information provided by the atlas is needed by local governments, State agencies, the general public, and others concerned about responsible development, environmental protection, and emergency preparedness. The atlas was inspired by the Atlas of Coastal Hazards, which 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. All map data and text will be available on a CD-ROM to allow users to make custom maps using a personal computer and Geographic Information System browsing software. In 1998 we compiled the data for the Galveston Bay area. The second year of the project will focus on the Sabine Lake area.

Coastal Processes, Shoreline Changes, and Shoreline Protection Options, Magnolia Beach Area, Calhoun County, Texas

Robert A. Morton, principal investigator

Residents of the Alamo Beach–Magnolia Beach–Indianola area of Calhoun County have witnessed long-term gradual bluff and beach retreat along most segments of the west shore of Matagorda and Lavaca Bays between Gallinipper Point and the mouth of Powderhorn Lake. This beach erosion has consumed private property, destroyed the historic town site of Indianola, and, if left unabated, currently threatens to destroy segments of the primary access road, houses, and some business establishments.

The purpose of this study was to analyze the geological setting and physical processes that control beach erosion near Magnolia Beach and to recommend erosion-mitigation options that are cost effective and that have negligible environmental impacts. The 1-year study conducted by the Bureau in cooperation with Shiner Moseley and Associates was sponsored by the Golden Crescent Regional Planning Commission with funding from the Texas General Land Office Coastal Management Program and Calhoun County.

The study involved surveying topographic beach profiles and making field observations regarding sediment textures, wave and current conditions, sediment-transport directions, and prior attempts to stop beach erosion. We compared wave energy associated with winter storms with energy associated with ship waves to evaluate the impact of increased ship traffic in the Matagorda Ship Channel. In addition, we prepared a combined geological and coastal-engineering report that presents the findings of the study and makes recommendations that pertain to beach use and shoreline protection.

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

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

Scientists from the Bureau and the Department of Geological Sciences are working with students from Ball High School in Galveston, Texas, on this coastal research project funded by the Texas Coastal Management Program, Conoco, and the Exxon Foundation. 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 along-shore drift, and dune vegetation. They 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. During our first year, we developed classroom materials, field techniques, and part of a curriculum. We are continuing the program for a second year at Ball High School, and two more schools will enter the program in 1999.

Mapping Shoreline Types of the Central Texas Coast

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

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 1998, the Bureau completed classifying and ranking 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-scale 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).

Final products of the project include digital files of the shoreline classifications and a report that describes the shoreline types and presents examples from the study area.

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

James C. Gibeaut and Bob E. Schutz (Center for Space Research, The University of Texas at Austin), principal investigators; Roberto Gutierrez and Robert A. Morton; assisted by Eric M. Matzel, Cheng-Fang Lo, and Sung Byun

The development of coastal-sediment budgets and models for sediment transport and shoreline change require bathymetric surveys having vertical resolution and accuracy of 5 cm or better. Horizontal resolution and accuracy need to be at least 10 cm to quantify bedforms and bars. Typical surveys conducted for navigational chart making and dredging operations are two to four times less accurate than what is desired for coastal studies. This project is developing a survey system to improve the accuracy of coastal bathymetric surveys for research purposes. It is a joint project with the Center for Space Research (CSR) at The University of Texas at Austin and is funded by the Texas Higher Education Coordinating Board under the Texas Advanced Technology Program.

We are developing a high-accuracy, high-resolution bathymetric surveying system (HARBSS) that overcomes the confounding effects of changing vessel draft, waves, and tides on depth soundings and that eliminates the need for measuring and modeling water level for a particular survey. The system combines Global Positioning System (GPS) receivers, an electronic motion sensor, a digital-gyro compass, a digital-analog echo sounder, a conductivity-temperature-depth probe (CTD), a computer, and custom software. The GPS antenna, compass, and motion sensor are aligned with the echo sounder's transducer. Using a bias-free phase solution from the GPS data (X, Y, Z accuracy of better than 3 cm), attitude information from the motion sensor, and heading information from the compass, we determine the position and aim of the transducer for each sounding. The CTD provides data to calculate the speed of sound. Using the above data, we correct the sounding depths and horizontal locations of sounding points in X, Y, and Z with respect to an Earth-centered ellipsoid.

Real-time, 3-D (X, Y, Z) GPS positioning accurate to 3 cm is critical to achieving our survey goals. We require this accurate positioning once per second while the vessel is in motion. To solve for the position of a moving boat, typical GPS software requires a static initialization. The boat must remain on land and absolutely stationary for several minutes. Otherwise, the software must process many more minutes of kinematic (moving) data before it can converge on a "best" initial position. CSR has designed a software algorithm that uses only 1 second of GPS data to compute the initial position of a moving boat. The Multi-Stage, Least-Squares Search (MSLSS) method allows near-instantaneous boat positioning without static initialization. If the GPS receiver on the survey boat loses "lock" on the GPS satellite signals because of obstructions or radio interference, the MSLSS algorithm can update the GPS position in just 1 to 2 seconds once GPS signals are reacquired.

Tests conducted on a lake show that in constant and uniform speed-of-sound conditions, HARBSS can provide soundings that are within 5.2 cm (mean error) of their true elevations. Horizontal accuracy is estimated to be within 10 cm. This accuracy can be achieved from a small, open boat that is rolling, pitching, heaving, or listing. Error analysis indicates that we may be able to decrease the error by one-half with better synchronization and interpolation of the various data streams.

Patterns of Shoreline Change and Hurricane Washover on Barrier Islands

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

Despite the erosional nature of barrier islands and spits, they have become highly developed and continue to develop along much of the U.S. coast. This activity has altered erosional and depositional patterns of shorelines. Development has placed property and lives at risk from coastal storms, sea-level rise, and long-term erosion and has affected coastal habitats. To understand the dynamics of coasts, we need to measure the exchange of sediment between dune, beach, and nearshore environments. What has been lacking, however, is a way to collect detailed and accurate topographic and bathymetric data rapidly along tens of kilometers of shoreline. Recent advances in airborne laser ranging and application of the Global Positioning System (GPS) can overcome this survey problem.

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

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

Assistance to State Agencies Regarding Coastal Issues

Robert A. Morton, principal investigator

In 1998, 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.

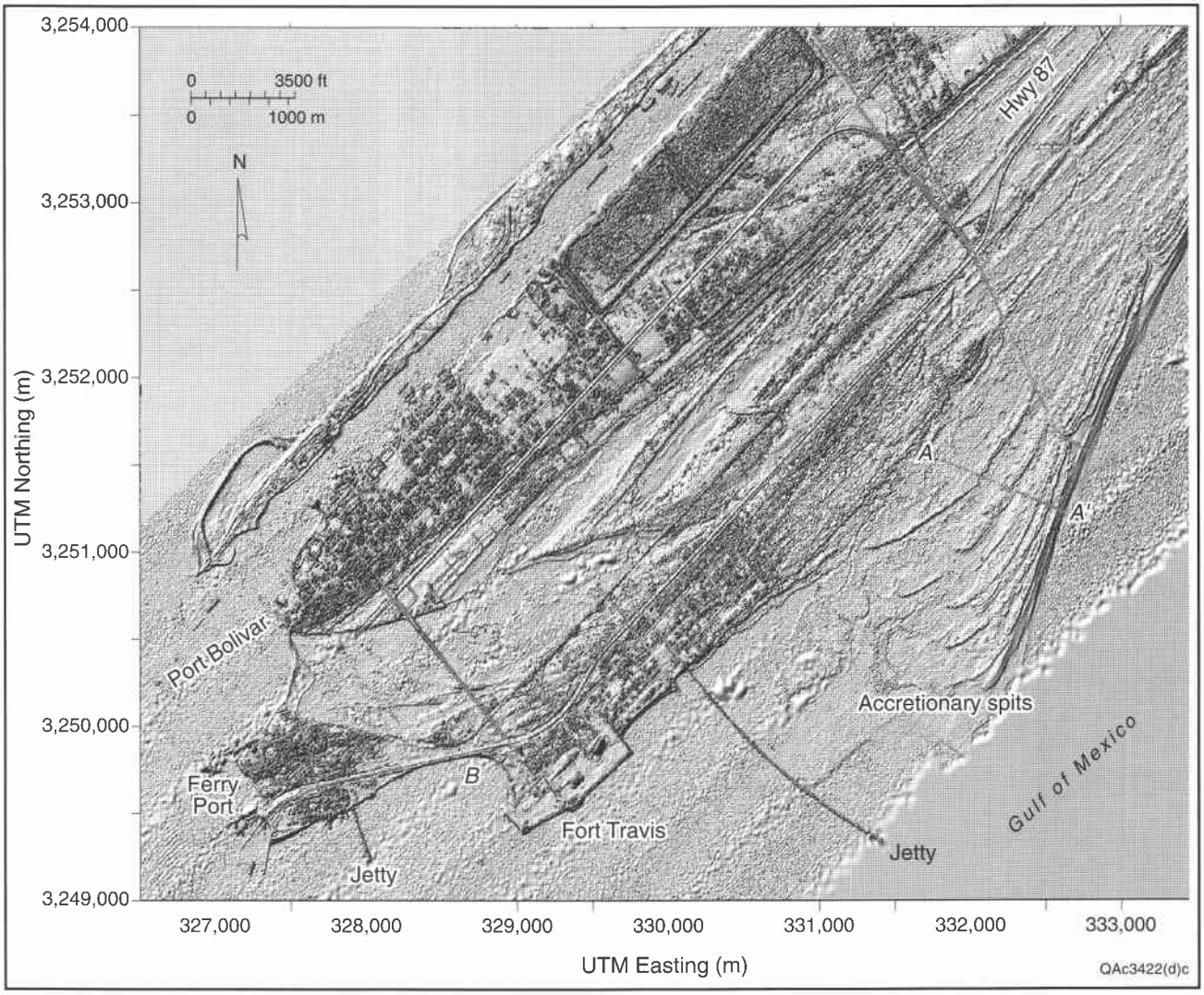
We assisted the Texas General Land Office, Natural Resource Damage Assessment Division, by analyzing land loss and shoreline changes at Shamrock Island in Corpus Christi Bay. We also made recommendations regarding protection of the wetlands and mitigation of beach erosion.

In addition, we assisted the Texas General Land Office, Coastal Division, 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, all of whom are considering wetlands restoration or protection in Galveston Bay, Sabine Valley, and Corpus Christi Bay.

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

Robert A. Morton, principal investigator;
Robin C. Nava and William A. White; George H. Ward
(Center for Research in Water Resources,
The University of Texas at Austin);
assisted by James E. Lundy

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



Shaded-relief topographic image of the Port Bolivar area on the west end of Bolivar Peninsula, Texas Gulf Coast. The image, which covers a 7- × 5-km area, has a spatial resolution of 5 m and comprises 3.8 million ALTM laser points. The Intracoastal Waterway barge traffic is visible along the upper left-hand edge of the image. Vegetation and cultural features (roads, buildings, and jetties) are clearly discernible. A large, rectangular pile of dredge spoil forms a topographic high to the northeast of Port Bolivar. Identifiable geomorphic features include the shoreline, beach and foredunes, recurved spits, beach ridges, and small tidal creeks. The recurved spits and tidal flats immediately northeast of Bolivar Road's North Jetty represent the current site of peninsular accretion, more than 5 m/yr of seaward advance. In the center of the peninsula are a series of straight beach ridges that represent an earlier stage in the peninsula's accretion.

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 fishery 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 that have impacted 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 1998 we completed a quantitative 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 worked with Espey Huston and Associates to collect and analyze samples from the placement areas that were used to evaluate geotechnical properties such as density, void ratios, and water contents. These analyses allowed us to differentiate between volume loss attributed to sediment reworking versus losses associated with compaction and dewatering.

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.

We also evaluated several experimental designs (submerged berm, emergent berm, shallow mound) that were constructed to retain dredged material in one of the high shoaling areas. A comprehensive report was prepared that presented the data and summarized the technical findings of the study.

Mapping Investigations

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; Thomas A. Tremblay, Gregory J. Jeffers, John R. Andrews, and Sarah B. Dale

This project consists of three subprojects that will produce geologic maps to 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 of Economic Geology.

Mapping for the south-central Texas subproject is being done in three geologically critical areas: the west San Antonio, Austin–Georgetown, and Del Rio corridors. This is the final year of mapping in these study areas. All three areas are within the Balcones Fault Zone, which is the main structural control on the geology of the region, and the Edwards aquifer. One subproject involves the geologic mapping of 7.5-minute quadrangles to support responsible development in karst aquifer areas in south-central Texas. The purpose of this project is to develop geologic base maps that are sufficiently detailed and accurate to meet the needs of a variety of professionals who must respond to the demands placed on the environment and resources of a south-central Texas region that is undergoing rapid urban growth. An improved geologic base 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 necessary for responsible urban development and construction needs. Geologic maps produced for this project are ultimately intended to be compiled in a digital format and utilized at a base scale of 1:100,000.

A second subproject will produce geologic maps of four quadrangles that are in areas of special environmental concern. Mapping will be completed during the first part of 1999. The map areas are along the Edwards and Trinity aquifer recharge zones, local aquifers, and rivers that are potentially being contaminated by leaking oil wells, pits, or pipelines. Improved geologic information in these areas can impact development, land use, public education, and the economy.

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

Other Geologic Investigations

Geomorphic Studies of Archeological Sites

L. Edwin Garner, principal investigator

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

The geomorphic studies are conducted to determine the geomorphologic character of locales, the influences on past human activities, and the effects of natural processes on deposits of cultural materials. Investigations during 1998 included thin-section examination of archeological materials and drilling projects in Brazoria and Nueces Counties.

Research Staff Activities

Lectures and Public Addresses

Robert E. Barba, Jr.

"Frac treatment optimization using measured input data": presented as a Society of Petroleum Engineers Distinguished Lecturer presentation to the Houston Advanced Well Stimulation Seminar, Houston, Texas.

Roger Barnaby

"Reservoir heterogeneity of turbidite channel/levee and submarine fan facies in a Lower Devonian chert and siliceous carbonate reservoir": presented at the West Texas Geological Society Fall Symposium, Midland, Texas.

"Stratigraphic framework, facies architecture, and interwell-scale heterogeneity of a mixed carbonate-siliciclastic shallow-water platform succession: Grayburg Formation (middle Guadalupian), New Mexico": presented at the weekly soft rock seminar at the Department of Geological Sciences, The University of Texas at Austin, Austin, Texas.

Sigrid J. Clift

"Geology as a career": presented to the Junior League Hispanic Mother/Daughter Program Career Fair, sponsored by the School of Social Work, The University of Texas at Austin, Austin, Texas.

Edward W. Collins

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

Alan R. Dutton

"Application of environmental assessment to remediation of abandoned oil field sites": presented at the Railroad Commission of Texas Regional Technology Transfer Conference, Houston, Texas.

"Determination of Texas oil fields eligible for variance from AOR requirements in UIC regulations for Class II injection wells": presented at the Railroad Commission of Texas Regional Technology Transfer Conferences, Midland and Dallas, Texas.

Shirley P. Dutton

"Incorporation of core data into reservoir characterization of a deep-water channel-levee and lobe deposit, Ford Geraldine unit": talk, poster, and core display presented to the Sixth Archie Conference, Kerrville, Texas.

William L. Fisher

"Natural gas supply: a resource and technology outlook": presented to the Natural Gas Supply Association, Executive Conference, Houston, Texas.

"Fossil fuels and global warming: how big a threat?": presented to the Independent Petroleum Producers Association of America, Houston, Texas.

"Technology, geologic ingenuity, and the great turnaround in natural gas": keynote presentation to the symposium on Macroeconomics of Oil and Gas, Houston Geological Society 75th Anniversary Celebration, Houston, Texas.

"Global oil and domestic gas: state of the industry": presented to the 35th Annual Meeting of the Society of Professional Earth Scientists, Durango, Colorado.

"Fossil fuels–from running out to fouling up": keynote presentation to the American Institute of Professional Geologists Annual Meeting, Baton Rouge, Louisiana.

"Meeting global resources needs": keynote presentation to the American Association of Petroleum Geologists, Division of Environmental Geosciences, Conference on Meeting Societal Resource and Environmental Requirements for the 21st Century, Taos, New Mexico.

"Energy and the environment: the technological solution": presented to The University of Texas Learning Advancement for Mature People (LAMP), Austin, Texas.

"Prices and technology in the oil patch": keynote presentation to the Texas Independent Producers and Royalty Owners, San Antonio, Texas.

"Technology and changing perceptions in oil and natural gas": presented at the Railroad Commission of Texas, Regional Technology Transfer Conference, Houston, Texas.

"Energy availability": presented to the symposium on The Lessons Learned: Preparedness 1941–1998, sponsored by the Admiral Nimitz Museum, U.S. Naval Academy and Texas Parks and Wildlife Department, Fredericksburg, Texas.

"Citation for Peter R. Rose, Ben H. Parker Medalist": presented to the American Institute of Professional Geologists, Baton Rouge, Louisiana.

"Citation for Charles G. Groat, Ian Campbell Medalist": presented to the American Geological Institute, Toronto, Ontario, Canada.

"Citation for Don R. Boyd, Hall of Honor inductee": presented to The University of Texas at Austin, College of Natural Sciences, Austin, Texas.

James C. Gibeaut

"Patterns of shoreline movement in Texas" and "Global positioning system, lasers, and emery rods: measuring the Texas shoreline": presented at the Texas Coastal Issues Conference, Galveston, Texas.

Douglas S. Hamilton

"Fluvial reservoir architecture": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 383R), Austin, Texas.

Bob A. Hardage

"Detecting thin-bed reservoirs in a low-accommodation setting with 3-D seismic attributes": presented to Landmark Users Group, Dallas, Texas.

"Emerging 3-D seismic technologies": presented at Railroad Commission State of Industry Seminar, Austin, Texas.

"Field-test results of seismic shear-wave imaging in the Appalachian Basin": presented to the U.S. Department of Energy Project Review Panel, Morgantown, West Virginia.

"Overview of seismic vector-wavefield applications": presented to The University of Texas at Austin, Geology Seminar Series, Austin, Texas.

"Seismic vector-wavefield applications in prospect evaluation": presented at Luncheon Speaker Series, Midland College, Midland, Texas.

"3-D seismic evidence of carbonate karst collapse": presented at the Railroad Commission of Texas Regional Technology Transfer Conference, Midland, Texas.

"3-D seismic evidence of the effect of carbonate karst collapse on overlying clastic stratigraphy" and "3-D seismic imaging and attribute analysis of genetic sequences deposited in low-accommodation conditions": presented at Landmark Worldwide Technology Forum, Houston, Texas.

"3-D seismic examples of karst-dependent reservoir compartmentalization": presented at the Railroad Commission of Texas Regional Technology Transfer Conference, Dallas, Texas.

"Vector-wavefield seismic stratigraphy": presented at Flagship Geoscience Software Seminar, Houston, Texas.

Tucker F. Hentz

"Play concepts and data compilation for the offshore Gulf of Mexico atlases": presented to the Geospatial Information and Technology Association, Houston, Texas.

Susan D. Hovorka

"Determining water depth from evaporite sediments—a key element in modeling basin evolution": presented to The University of Texas at Arlington, Department of Geology, Arlington, Texas.

"Edwards aquifer issues and scientific resolution" and "Edwards aquifer field trip stops 3 and 4": presented to the Comisión Nacionál del Agua, Austin, Texas.

"Synsedimentary dissolution, a method for determining water depth in evaporites": presented to the SEPM Evaporite Research Group, American Association of Petroleum Geologists Annual Convention, Salt Lake City, Utah.

Martin P. A. Jackson

"Overview of AGL research for 1998," "What determines whether roho or counterregional systems form?", "Role of subaerial volcanic rocks and major unconformities in South Atlantic salt systems," "Salt-tectonic provinces across continental-oceanic boundary in Lower Congo Basin, South Atlantic margin," and "Seismic-based research in salt tectonics": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

James W. Jennings, Jr.

"How much core-sample variance should a well log model reproduce?": presented to Texas A&M University, Department of Petroleum Engineering graduate seminar, College Station, Texas.

Charles Kerans

"AAPG current processes and technologies: recent advances in sequence stratigraphy for reservoir characterization": presented to the American Association of Petroleum Geologists Annual Convention, Salt Lake City, Utah.

"Forward modeling of the Permian Basin," "Fundamentals of carbonate sequence stratigraphy," "Tools of carbonate sequence stratigraphy," "Contrasting styles of carbonate ramp development, Permian of West Texas and Cretaceous of South Texas," "High-frequency sequence stratigraphy and the new sedimentology," and "Ramp-to-rim evolution in the Permian stratigraphy of the Delaware Basin": presented to The University of Texas at Austin, Department of Geological Sciences, Qualline Lecture Series, Austin, Texas.

"Sequence stratigraphy of Cretaceous carbonate ramp systems": presented to the Fort Worth Geological Society, Fort Worth, Texas.

Stephen E. Laubach

"The challenges of reservoir structural analysis in the 21st Century" and "Web-based professional group information exchange": presented at the American Association of Petroleum Geologists, Reservoir Deformation Research Group Annual Meeting, Salt Lake City, Utah.

"Fractured reservoir analysis: implications for the petroleum engineer": presented at The University of Texas at Austin, Department of Petroleum and Geosystems Engineering, Departmental Seminar, Austin, Texas.

"Future issues in rock mechanics in the petroleum industry": presented at American Rock Mechanics Symposium, Pacific Grove, California.

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

"Origin of subsurface fractures": invited keynote presentation at The Woodworth Conference of the Geological Society of London, Coleraine, Northern Ireland.

"Practical tools for fractured reservoirs": presented at the Rocky Mountain Association of Geologists Symposium ("Fractured reservoirs: practical exploration and development strategies"), Denver, Colorado.

"Quantitative approaches to description of subsurface structures": presented at Texas A&M University, College Station, Texas.

Joel Le Calvez

"Graben and diapir relays and their tectonic inversion": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

F. Jerry Lucia

"The conformance of diagenetic products and depositional textures and its impact on predicting permeability distribution in carbonate reservoirs": presented at the Archie Conference, Kerrville, Texas.

"Defining flow units for reservoir characterization": presented at the Society of Petroleum Engineers Forum, "Impact of pore-scale to well-test scale data relationships," Breckenridge, Colorado.

"Location of remaining oil in San Andres and Grayburg reservoirs: so where is the remaining 65 percent?": presented to the Society of Petroleum Engineers, Midland, Texas.

"Rock fabric approach to petrophysical quantification of geologic descriptions: Shuaiba (middle Cretaceous) reservoir, Idd el Shargi field": presented at the GEO98 Conference, Bahrain.

Robert E. Mace

"Contaminant plumes beneath leaking petroleum storage tank sites in Texas": presented to the Austin Geological Society, Austin, Texas.

"Effect of well storage, turbulent flow, and barometric effects on well tests": presented to The University of Texas at Austin, Department of Civil Engineering (CE 374L), Austin, Texas.

"MTBE plumathon study in Texas": presented at the Petroleum Environmental Research Forum, Brea, California.

"MTBE plumes in Texas": presented the Industry Council on the Environment, Austin, Texas.

"Numerical modeling of ground-water flow and contaminant transport": presented to The University of Texas at Austin, Department of Civil Engineering (CE 394K), Austin, Texas.

"Numerical modeling of ground-water flow in the Ogallala aquifer in Texas: past, present, and future": presented to the Panhandle Regional Planning Group, Amarillo, Texas.

"Superposition and image well theory": presented to The University of Texas at Austin, Department of Civil Engineering (CE 374L), Austin, Texas.

R. P. Major

"Introduction to the State of Texas Advanced Resource Recovery (STARR) project": presented to the Texas Oil and Gas Forum, Austin, Texas.

Robert A. Morton

"Analysis of beach erosion and its causes, Magnolia Beach Area, Calhoun County": presented to public officials and the Citizens Advisory Committee, Port Lavaca, Texas.

"Sediment budget and sediment reworking in Laguna Madre": presented at the meeting of the Laguna Madre Interagency Coordinating Team, Austin Texas.

Jeffrey G. Paine

"Geophysical investigations at the Montague County site": presented at the District Oil-Field Cleanup Coordinators' Conference, Austin, Texas.

Jay A. Raney

"Initial results of characterization studies of the Delta del Orinoco, Venezuela": presented to Petróleos de Venezuela, S.A., and Universidad Simón Bolívar, Caracas, Venezuela.

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

Stephen C. Ruppel

"Current directions in carbonate reservoir characterization": presented to Midland College, Midland, Texas.

Bridget R. Scanlon

"Evaluation of water fluxes and ages in an arid setting": presented to The University of Texas at Austin, Department of Petroleum and Geosystems Engineering, Austin, Texas.

"Monitoring techniques related to subsurface gas transport": presented to the University of Arizona, Maricopa Experimental Station, Phoenix, Arizona.

"Uncertainties in estimating water fluxes and dating pore water in an arid unsaturated system": presented to the European Geophysical Society, Nice, France.

Daniel D. Schultz-Ela

"Inferring structures beneath salt sheets: numerical models of coupling between subsalt and suprasalt deformation" and "Numerical modeling of extensional salt tectonics in the Grabens in Canyonlands National Park, Utah": presented to Rice University, Department of Geology and Geophysics, Houston, Texas.

"Sliding on a slippery slope: numerical modeling and salt tectonics applied to the Grabens in Canyonlands National Park": presented to Baylor University, Department of Geology, Waco, Texas.

"What determines whether roho or counterregional systems form?", "Effect of slope changes on sequence of pre-raft formation: relevance to The Grabens (Utah) and

West Africa," and "Preliminary results from 3-D numerical modeling of contraction": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

Andrew R. Scott

"Improvement of reservoir quality through microbially enhanced coalbed methane: MECoM": presented at the International Conference on Coal Seam Gas and Oil, Simulation and Modeling of Hydrocarbon Generation Session, Brisbane, Australia.

"The application of a coalbed methane producibility model in defining exploration fairways in the San Juan Basin, Rocky Mountain Foreland": presented at the Society of Independent Professional Earth Scientists National Meeting, Tamarron, Colorado.

"Fracture trends in the Medina Sandstone, Henderson Dome Area": presented to the U.S. Department of Energy, Morgantown, West Virginia.

James L. Simmons, Jr.

"Multicomponent vector seismology": presented to the Petroleum Technology Transfer Council, Morgantown, West Virginia.

Rebecca C. Smyth

"Striking oil at 20 ft: a petroleum geologist's dream or a hydrogeologist's nightmare": presented to The University of Texas at Austin, Department of Geological Sciences, Hydrogeology Brown Bag Seminar, Austin, Texas.

Noel Tyler

"Optimizing production in East Texas field": presented to East Texas field producers group, Kilgore, Texas.

"Progress report on National Research Council Panel to review United States Geological Survey Energy Program": presented to the Committee on Earth Resources, National Research Council, Washington, DC.

Roger Tyler

"Defining coalbed methane exploration fairways": presented to the International Conference on Coal Seam Gas and Oil, Simulation and Modeling of Hydrocarbon Generation Session, Brisbane, Australia.

"Developing coalbed methane exploration fairways": presented to the Society for Mining, Metallurgy, and Exploration, Inc., Central Texas Mining Section, Austin, Texas.

"Project STARR—the State of Texas Advanced Oil and Gas Resource Recovery program": presented at the Society of Independent Professional Earth Scientists National Meeting, Durango, Colorado.

"State of Texas Advanced Resource Recovery project (STARR)": presented at the Railroad Commission of Texas Regional Technology Transfer Conferences, Houston and Midland, Texas.

Vendeville, Bruno

"Dynamically scaled modeling of geologic deformation: applications to understanding salt structures": presented to The University of Texas at Austin, Department of Petroleum and Geosystems Engineering, Austin, Texas.

"Geological background and rationale for 1998 experiments," "Graben and diapir relays and their tectonic inversion," "Reactivation of salt ridges around minibasins during progradation and margin uplift," "3-D evolution of reactivated minibasins," "Subsalt faulting and thin-skinned extension of preexisting depocenters": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

William A. White

"Status and trends of selected coastal habitats in the Corpus Christi Bay National Estuary Project study area": presented to the Corpus Christi Bay National Estuary Program Management & Scientific and Technical Advisory Committees, Corpus Christi, Texas.

Brian J. Willis

"Architecture of fluvial-dominated valley-fill deposits in the Cretaceous Fall River Formation": presented to Indiana University, Department of Geological Sciences, Research Colloquium, Bloomington, Indiana.

"Architecture of a tide-influenced delta in the Cretaceous Frewens Castle Sandstone, Frontier Formation, Wyoming": presented to Indiana University, Department of Geological Sciences, Sedimentology Talk, Bloomington, Indiana.

Bureau of Economic Geology Seminars

H. Scott Hamlin

"Slope and basin-floor depositional systems, Ozona Sandstone, Val Verde Basin, southwest Texas"

Mark H. Holtz

"Reservoir characterization of Keystone East Holt field: modeling restricted platform carbonates"

Martin P. A. Jackson

"Salt-fault interactions in the Gulf of Mexico"

James W. Jennings, Jr.

"Geostatistical analysis and simulation of petrophysical data from carbonate outcrops"

Stephen E. Laubach

"Current research on reservoir fractures"

Robert E. Mace

"Spatial and temporal variability of MTBE plumes beneath gasoline stations in Texas"

Jay A. Raney

"Geo-environmental characterization of the Orinoco Delta, Venezuela"

Andrew R. Scott (with Roger Tyler)

"The potential for developing coalbed gas resources along the North Slope of rural Alaska—a walk on the wild side"

Roger Tyler (with Andrew R. Scott)

"The potential for developing coalbed gas resources along the North Slope of rural Alaska—a walk on the wild side"

Mark R. Vining

"Prospecting in the Texas Gulf Coast Frio Formation using 3-D seismic data and reservoir volumetrics: Umbrella Point field, Chambers County, Texas"

Lesli J. Wood

"Integrated sequence stratigraphy and seismic attribute technologies for resolving complex fluvial reservoir geometries, San Jorge Basin, Argentina"

Hongliu Zeng

"Stratal slicing: methodology and applications"

Congressional, Legislative, and Special Testimony

Alan R. Dutton

"Hydrogeologic investigations of the proposed Eagle Flat site of the Texas low-level radioactive waste repository": presented to the State Office of Administrative Hearings on behalf of the Texas Low-Level Radioactive Waste Disposal Authority, Austin, Texas.

James C. Gibeaut

"Coastal erosion research at the Bureau of Economic Geology": presented to the Texas House of Representatives, Committee on Land and Resource Management, Austin, Texas.

Jay A. Raney

"Geologic studies to characterize the proposed site of the Texas Low-Level Radioactive Waste Disposal facility": presented to the State Office of Administrative Hearings on behalf of the Texas Low-Level Radioactive Waste Disposal Authority, El Paso and Austin, Texas.

Bridget R. Scanlon

"License application for the Texas Low-Level Radioactive Waste Disposal site": presented to the State Office of Administrative Hearings on behalf of the Texas Low-Level Radioactive Waste Disposal Authority, El Paso and Austin, Texas.

Committee Services, Offices, and Other Professional Responsibilities

Sigrid J. Clift

Co-chairperson, Texas Environment Awareness Network (TEAN), representing the Bureau of Economic Geology.

Edward W. Collins

President, Austin Geological Society (1998–1999 term).

President-elect, Austin Geological Society (1997–1998 term).

Alan R. Dutton

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

Member, Technical Advisory Group, Edwards Aquifer Authority, for developing an Edwards Aquifer Optimization Program.

Shirley P. Dutton

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

Convenor, "Role of fluid flux in diagenesis," technical session, American Association of Petroleum Geologists 1999 Annual Convention.

Co-leader of field trip, "Geology of West Texas oil reservoirs," Chairman of the Railroad Commission of Texas, West Texas.

William L. Fisher

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

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

Chairman, Search Committee,
American Institute of Professional Geologists.

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

Vice Chairman, World Energy Congress, Division 2.1.

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

Foundation Trustee, American Geological Institute.

Trustee, Southwest Research Institute.

Trustee Associate, American Association of
Petroleum Geologists Foundation.

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

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

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

Member, Advisory Council, Gas Research Institute.

Member, 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, National Academy of Engineering.

Member, Technical Program Committee,
World Energy Conference.

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

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.

William E. Galloway

Member, Admissions and Support Committee,
The University of Texas at Austin.

SEPM Technical Program Chairman,
1999 AAPG/SEPM Annual Convention.

Poster Session Chairman, 1998,
AAPG/SEPM Annual Convention.

Member, SEPM Research Concepts Committee.

James C. Gibeaut

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

Member, Coastal Hazards Theme Team,
National Aeronautic and Space Administration.

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

Douglas S. Hamilton

Associate Editor,
Journal of Petroleum Science and Engineering.

Member, Program Advisory Committee, 1999 Gulf Coast
Section SEPM Foundation Research Conference.

Bob A. Hardage

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

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

Member, Organizing Committee,
Borehole Profile Workshop, Stavanger, Norway.

Member, Publications Committee,
Society of Exploration Geophysicists.

Member, Development and Production Committee,
Society of Exploration Geophysicists.

Member, Program Advisory Committee, 1999 Gulf Coast
Section SEPM Foundation Research Conference.

Tucker F. Hentz

Conference volume technical editor, 1999 Gulf Coast
Section SEPM Foundation Research Conference.

Martin P. A. Jackson

Member, International Union of Geological Sciences
Commission on Tectonics.

James W. Jennings, Jr.

Member, Conference Organizing Committee,
1998 Gordon Research Conference on Modeling of
Flow in Permeable Media.

Chairman, "Quantitative geological descriptions,"
technical session, 1998 Gordon Research Conference
on Modeling of Flow in Permeable Media.

Charles Kerans

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

Member, Development Geology Committee,
Society of Petroleum Engineers.

Stephen E. Laubach

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

Chairman, "Micromechanics and flow," technical session,
U.S. Department of Energy Basic Energy Sciences,
1998 Research Symposium, Santa Fe, New Mexico.

Member, Research Committee,
American Association of Petroleum Geologists.

Member, Editorial Board, *SPE Formation Evaluation*, Society of Petroleum Engineers.

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

F. Jerry Lucia

Chairman, "Facies and sequence stratigraphic characterization of reservoir: postdrilling results," technical session, SEPM (Society for Sedimentary Geology) Annual Conference.

Chairman, "Geologic and petrophysical definition of flow units," technical session, Society of Petroleum Engineers Annual Conference.

Robert E. Mace

Treasurer, Austin Geological Society.

Judge, Senior Division Environmental Science, Texas State Science Fair.

R. P. Major

Chairman, Poster Session Program Committee, SEPM (Society for Sedimentary Geology), 1999 American Association of Petroleum Geologists Annual Convention.

President-Elect, Gulf Coast Section, Society of Economic Paleontologists and Mineralogists.

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).

Jerry W. Mullican

Member, Ground Water Protection Council.

President, Underground Injection Practices Research Foundation.

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

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

Jeffrey G. Paine

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

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

Jay A. Raney

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, Deputy Caucus, Association of American State Geologists.

Douglas C. Ratcliff

Member, Transactions on CD-ROM Committee, Gulf Coast Association of Geological Societies.

Stephen C. Ruppel

Delegate, American Association of Petroleum Geologists House of Delegates.

Chairman, Publications Committee, Austin Geological Society.

Member, Program Advisory Committee, 1999 Gulf Coast Section SEPM Foundation Research Conference.

Bridget R. Scanlon

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

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

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

Convenor, "Recent advances in tracers in vadose zone hydrology," technical session, European Geophysical Union, Nice, France.

Convenor, "Monitoring and modeling of the performance of engineered covers for waste isolation," technical session, American Geophysical Union Annual Meeting.

Daniel D. Schultz-Ela

Convenor, "Structure and rheology of the crust and lithosphere posters," technical session, American Geophysical Union Annual Fall Meeting.

Andrew R. Scott

Co-chairman and co-convenor, "Coalbed methane and tight gas sandstones," technical session, Energy Mineral Division, American Association of Petroleum Geologists 1999 Annual Convention.

Co-coordinator of workshop, "Geologic and hydrologic controls critical to coalbed methane production and resource assessment—the United States experience: analogs useful for Australian coal basins," International Conference on Coal Seam Gas and Oil, Brisbane, Australia.

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

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

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

Convenor, "Simulation/modeling of hydrocarbon generation," technical session, International Conference

on Coal Seam Gas and Oil, Brisbane, Australia.

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

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

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

James L. Simmons, Jr.

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

Noel Tyler

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

Chairman, 1999 Advanced Reservoir Characterization for the Twenty-First Century Research Conference, Gulf Coast Section of SEPM (Society for Sedimentary Geology).

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

Member, National Research Council Panel to review United States Geological Survey Energy Program.

Member, Committee on Earth Resources, National Research Council.

Member, University Advisory Board, Energy Council.

Member, President's Advisory Committee for Vice President of Research.

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

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

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

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

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

Member, Texas Mapping Advisory Committee.

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

Roger Tyler

Chairman, "Source of oil and gas," technical session, International Conference on Coal Seam Gas and Oil, Brisbane, Australia.

Co-chairman and co-convenor, "Coalbed methane and tight gas sandstones," technical session, Energy Mineral Division, American Association of Petroleum Geologists 1999 Annual Convention.

Co-coordinator of workshop, "Geologic and hydrologic controls critical to coalbed methane production and resource assessment—the United States experience: analogs useful for Australian coal basins," International Conference on Coal Seam Gas and Oil, Brisbane, Australia.

Member, South African Council for Natural Scientists.

Bruno C. Vendeville

Member, Editorial Board, *Tectonophysics.*

Convenor, "From the Arctic to the Mediterranean: salt, shale and igneous diapirs in and around Europe," symposium, European Geophysical Society XXIII General Assembly, Nice, France.

Chairman, "Deepwater structure II breakout session," American Association of Petroleum Geologists Hedberg Research Conference, "Integration of geologic models for understanding risk in the Gulf of Mexico," Galveston, Texas.

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.

William A. White

Member, Bessie Heights Marsh Restoration Planning Team, Texas Parks and Wildlife Department.

Brian J. Willis

Co-chairman, "Reservoir architecture of fluvial-deltaic sandstones," technical session, American Association of Petroleum Geologists Annual Convention.

Lesli J. Wood

Member, House of Delegates, American Association of Petroleum Geologists.

Wan Yang

Co-chairman, SEPM Technical Program, American Association of Petroleum Geologists 1999 Annual Convention.

Leader of field trip, "Karst development and cyclostratigraphy of the El Paso Group, Franklin Mountains, El Paso, Texas," delegation of China National Petroleum Corporation, West Texas.

University Teaching/ Continuing Education

Robert E. Barba, Jr.

"Economical fracture optimization for 3-D models": short course presented to the Society of Petroleum Engineers, Oklahoma City, Oklahoma.

Roger J. Barnaby

"Inefficient hydrocarbon recovery due to heterogeneity of turbidite channel/levee and submarine fan deposits of the Thirtyone Formation: University Waddell field" and "High-resolution, cycle-stratigraphic correlation and interpretation of Pennsylvanian shelf margin strata: key to improved understanding and description of reservoir heterogeneity: Block 9 field": co-lecturer of University Lands Advanced Recovery Initiative Workshop No. 2, "Application of modern concepts of reservoir characterization to defining remaining resource potential in University Lands fields," Midland, Texas.

Sigrid J. Clift

"New core-analysis methods applied to Permian Sandstone Pakenham (Wolfcamp) field, Terrell County": co-lecturer of workshop, "Natural fracture evaluation and reservoir-quality diagnosis: new methods and East Texas Basin examples," sponsored by the Petroleum Technology Transfer Council and Bureau of Economic Geology, The University of Texas at Austin, Tyler, Texas.

Alan R. Dutton

"Determination of Texas oil fields eligible for variance from AOR requirements": presented to workshop on "Area of review (AOR) requirements for oil field injection wells and application for variance," sponsored by the Railroad Commission of Texas, Houston, Dallas, and Lubbock, Texas.

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 and 171C), Austin, Texas (with William E. Galloway).

William E. Galloway

"Depositional systems and sequences in exploration for sandstone reservoirs": short course presented as AAPG Continuing Education Short Course, Houston, Texas.

"Trend and basin analysis": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 330K), Austin, Texas.

"Sedimentary basin analysis": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 383S), Austin, Texas.

"Terrigenous clastic depositional systems": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 383), Austin, Texas.

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

Jubal G. Grubb

"Preliminary analysis of reservoir heterogeneity in Wolfcamp platform carbonates, Block 9 field": co-lecturer of University Lands Advanced Recovery Initiative Workshop No. 2, "Application of modern concepts of reservoir characterization to defining remaining resource potential in University Lands fields," Midland, Texas.

C. Robertson Handford

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

"Carbonate sequence stratigraphy—interpretation of seismic and well log data": short course presented to the Houston Geological Society, Houston, Texas.

Bob A. Hardage

"Analysis of 3-D seismic data from the Waha–Lockridge area" and "Synthesis, recommendations, and concluding remarks": co-lecturer of workshop, "Integrated strategies for carbonate reservoir reserve growth: an example from the Ellenburger Group, Permian Basin, West Texas," sponsored by the Gas Research Institute; U.S. Department of Energy; Bureau of Economic Geology, The University of Texas at Austin; and Petroleum Technology Transfer Council, Midland and Houston, Texas.

"Applications of seismic technology for independent operators": short course presented to the American Association of Petroleum Geologists, Eastern Section Annual Meeting, Columbus, Ohio.

Tucker F. Hentz

"Geologic context and overview of the Waha–Lockridge project": co-lecturer of workshop, "Integrated strategies for carbonate reservoir reserve growth: an example from the Ellenburger Group, Permian Basin, West Texas," sponsored by the Gas Research Institute; U.S. Department of Energy; Bureau of Economic Geology, The University of Texas at Austin; and Petroleum Technology Transfer Council, Houston, Texas.

Mark H. Holtz

"Modern approaches to reservoir characterization of Permian platform carbonates in the Permian Basin": co-lecturer (with Stephen C. Ruppel) of short course presented to the Permian Basin Graduate Center, Midland, Texas.

Stephen E. Laubach

"The challenge of exploiting natural fractures," "Characterization methods," "Fracture quality:

key to tight gas sandstone evaluation," "How to identify and map fracture fairways," and "How to design a horizontal well in tight gas sandstone": presented at workshop, "New core-analysis methods applied to Permian Sandstone Pakenham (Wolfcamp) field, Terrell County," and co-lecturer of workshop, "Natural fracture evaluation and reservoir-quality diagnosis: new methods and East Texas Basin examples," sponsored by the Petroleum Technology Transfer Council and Bureau of Economic Geology, The University of Texas at Austin, Tyler, Texas.

"Current progress in fracture evaluation" and "Fracture orientation and fracture quality prediction case studies: lessons for practical application": co-lecturer of workshop ("New methods of fracture characterization and simulation"), Austin, Texas.

"Natural fracture evaluation and reservoir-quality diagnosis": presented at Department of Energy/Petroleum Technology Transfer Council workshop, Pittsburgh, Pennsylvania.

"Rapid prediction of fracture fluid flow": co-lecturer of workshop ("Geologic Studies of Fractures in Reservoirs") presented to the U.S. Department of Energy, Austin, Texas.

"Using microstructure observation to quantify reservoir properties and improve simulation": presented at Department of Energy/Petroleum Technology Transfer Council workshop, Midland, 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.

"Petrophysical heterogeneity and location of remaining oil, Fuhrman–Mascho San Andres Unit No. 124 well": co-lecturer of University Lands Advanced Recovery Initiative Workshop No. 2, "Application of modern concepts of reservoir characterization to defining remaining resource potential in University Lands fields," Midland, Texas.

Stephen C. Ruppel

"Unconformity-related porosity development in the San Andres Formation: Fuhrman–Mascho San Andres–Grayburg field": co-lecturer of University Lands Advanced Recovery Initiative Workshop No. 2, "Application of modern concepts of reservoir characterization to defining remaining resource potential in University Lands fields," Midland, Texas.

"Modern approaches to reservoir characterization of Permian platform carbonates in the Permian Basin": co-lecturer (with Mark H. Holtz) of short course presented to the Permian Basin Graduate Center, Midland, Texas.

Bridget R. Scanlon

"Ground water pollution and transport": presented to The University of Texas at Austin, Department of Civil Engineering (CE 394K), Austin, Texas.

Andrew R. Scott

"Geologic and hydrologic controls critical to coalbed methane production and resource assessment—the United States experience: analogs useful for Australian coal basins": co-lecturer of workshop presented to the International Conference on Coal Seam Gas and Oil, Brisbane, Australia.

"The Petroleum Technology Transfer Council and Texas producers": co-lecturer of workshop, "Oil recovery from naturally fractured reservoirs: field studies, modeling, and analytic methods," sponsored by the U.S. Department of Energy; BDM–Oklahoma; Bureau of Economic Geology, The University of Texas at Austin; and the Petroleum Technology Transfer Council, Midland, Texas.

James L. Simmons, Jr.

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

Noel Tyler

"Characterization of heterogeneous reservoirs": co-lecturer of short course presented to the University of Petroleum, Beijing, China.

"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).

Roger Tyler

"Geologic and hydrologic controls critical to coalbed methane production and resource assessment—the United States experience: analogs useful for Australian coal basins": co-lecturer of workshop presented to the International Conference on Coal Seam Gas and Oil, Brisbane, Australia.

Hongliu Zeng

"Characterization of heterogeneous reservoirs": co-lecturer of short course presented to the University of Petroleum, Beijing, China.

"Seismic-continuity analysis of the Waha–Lockridge field area": co-lecturer of workshop, "Integrated strategies for carbonate reservoir reserve growth: an example from the Ellenburger Group, Permian Basin, West Texas," sponsored by the Gas Research Institute; U.S. Department of Energy; Bureau of Economic Geology, The University of Texas at Austin; and Petroleum Technology Transfer Council, Midland and Houston, Texas.

Papers and Abstracts by Bureau Staff in Outside (Non-BEG) Publications

Papers

Ambrose, W. A., Mendez, Milton, **Akhter, M. S.,** Wang, F. P., and Alvarez, Regulo, 1998, Geological controls on remaining oil in Miocene fluvial and shoreface reservoirs in the Mioceno Norte area, Lake Maracaibo, Venezuela: Petroleum Geoscience, v. 4, p. 363–376.

Becker, M. R., **Lake, L. W.,** and **Tyler, Noel,** 1997, Fractal properties of braided fluvial deposits for characterization and simulation of reservoir heterogeneity: Society of Petroleum Engineers Paper SPE 38951, 9 p.

Burns, S. L., and **Laubach, S. E.,** 1998, Virtual Collaboratory™, Frac City™, facilitates geoscientific collaboration and technology transfer, *in* Proceedings, GIS: Geoscience Information Society, p. 111–115.

Dellagiarino, George, **Miller, L. A.,** and **Doenges, Susann,** eds., 1998, Proceedings, Fourth Symposium on Studies Related to Continental Margins—a summary of year-nine and year-ten activities: sponsored by Minerals Management Service, U.S. Department of the Interior, and Continental Margins Committee, Association of American State Geologists, 178 p.

Dunn, K. A., McLean, R. J. C., Upchurch, G. R., Jr., and **Folk, R. L.,** 1997, Enhancement of leaf fossilization by bacterial biofilms: Geology, v. 25, p. 1119–1122.

Dutton, S. P., Barton, M. D., Clift, S. J., and **Guzman, J. I.,** 1998, Ramsey Sandstone deep-water channel-levee and lobe deposits, Ford Geraldine unit, Reeves and Culberson Counties, Texas, *in* Stoudt, E. L., Dull, D. W., and Raines, M. R., eds., Permian Basin core workshop—DOE funded reservoir characterization projects: Permian Basin Section—SEPM (Society for Sedimentary Geology), Publication No. 98-40, 33 p.

Dutton, S. P., and **Willis, B. J.,** 1998, Comparison of outcrop and subsurface sandstone permeability distribution, Lower Cretaceous Fall River Formation, South Dakota and Wyoming: Journal of Sedimentary Research, v. 68, no. 5, p. 890–900.

Folk, R. L., 1998, Nannobacteria in the natural environment and in medicine: Alpe Adria Microbiology Journal, v. 7, no. 2, p. 87–95.

Folk, R. L., and **Lynch, F. L.,** 1998, Carbonaceous objects resembling nannobacteria in the Allende Meteorite, *in* Hoover, R. B., ed., Proceedings, SPIE: instruments, methods, and missions for astrobiology: The International Society for Optical Engineering, p. 112–122.

Galloway, W. E., 1998, Clastic depositional systems and sequences: applications to reservoir prediction, delineation, and characterization: The Leading Edge, February, p. 173–180.

Galloway, W. E., 1998, Siliciclastic slope and base-of-slope depositional systems: component facies, stratigraphic architecture, and classification: American Association of Petroleum Geologists Bulletin, v. 82, no. 4, p. 569–595.

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Services

Core Research Centers

The Bureau of Economic Geology manages two core research facilities, the Core Research Center (CRC) and the Midland Core Research Center (MCRC). The CRC, located adjacent to the Bureau of Economic Geology Research and Administration Office, houses one of the largest public collections of subsurface geological materials in the United States and is open Monday through Friday from 8:00 a.m. to 5:00 p.m. (CST). The Curator is George Bush. The repository, approximately 103,000 ft^2, houses nearly 50 linear miles of shelving. 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. Information about the CRC and MCRC can be accessed from the Web site, http://www.utexas.edu/research/beg/crc.html.

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 16,000 core samples and 75,000 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) 1998, the CRC received more than 300 visitors, who made transactions involving CRC inventory that included materials from more than 735 wells and required the transfer of more than 14,930 boxes of core to and from viewing and shipping areas.

New acquisitions in 1998 totaled 98 new core samples in excess of 329 boxes. Core samples were received from eight Bureau projects and from industry sources: Arizona Gas, Low-Level Waste Fiscal Year 1998, Mandi and Injecto, Montague County, Pantex AIP, Railroad Commission of Texas—Post Oak, Texas Department of Transportation—Archaeology, and Texas Department of Transportation—East Columbia. Donations were also received from Mike Blum, Delray Oil Incorporated, Devon Energy Corporation, and Clayton Williams Energy, Incorporated.

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, industry, governmental agencies, and other organizations and interested individuals.

Extensive data and information are available from the Bureau's Reading Room/Data Center, and members of the Bureau's research staff provide advisory and technical services in their areas of expertise. The Bureau's Public Information Geologist maintains files on mineral resources (both energy and nonenergy minerals) and general geology of specific areas of the state and assists patrons in locating answers to questions. During 1998, approximately 1,500 such requests were handled by L. Edwin Garner, the Public Information Geologist. In addition to dealing with these direct-inquiry responses, Bureau staff members have contributed to educational programs by making presentations to public school classes in the Austin area.

Publication Sales

Sales of Bureau publications reached an all-time Bureau high this year, totaling more than a quarter of a million dollars. Contributing to this success were corporate site licenses for the offshore atlases and numerous bulk orders from bookstores. The best-selling publications of the year were our page-sized maps, our geologic atlas sheets, and our guidebooks. Other popular items were our three seismic data sets, known as Boonsville (SW 7), Stratton (SW 3), and Waha (SW 8), and our most recent publications about 3-D seismic interpretation (GC 97-4, 97-5, and 98-1).

For our U.S. customers' convenience, we offer a toll-free phone number (1-888-839-4365) and a toll-free fax number (1-888-839-6277). We continue to maintain our Web site, http://www.utexas.edu/research/beg/pub.html, which features an online order form.

The Publications Sales Office is managed by Amanda R. Masterson, assisted each semester by students. This year's student assistants were Iliana M. Delgado, Katy K. Fuller, Niazi Malik, Kristin Neilson, and Wendy J. Zinke.

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

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 (RRC) with at least one copy of a well log for each new, deepened, or plugged well. A subsequent agreement with the RRC designated the Bureau as the entity responsible for providing public access to these logs. The RRC supplies paper 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 1998, the GLF had accumulated approximately 200,000 well logs of various types from the RRC, at a rate of 800 logs per month. All logs are entered into the GLF's computer data base. Historical logs (prior to 1985) from the RRC will eventually be housed in the GLF; about 50,000 of these logs have already been received.

Moreover, a collection of geophysical well logs for more than 500,000 wells that have been acquired for Bureau research projects and as donations is also housed in the GLF. As of May 1998, about 30,000 Bureau electric logs had been entered into the GLF data base; the remainder are accessible from manual files. Additional data in the Bureau's collection include microfiche copies of well logs for more than 240,000 wells; scout tickets and well records for more than 500,000 wells; driller's logs for about 400,000 Texas wells; and completion cards for more than 300,000 Texas wells. Recent acquisitions to the Bureau collection include about 60,000 geophysical logs from various parts of Texas.

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

Staff of the Data Center 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 are transferred to the Department of Geological Sciences library, the Elizabeth C. and Joseph C. Walter, Jr., Geology Library.

Support Staff

Administrative

Administrative staff members, supervised by Wanda L. LaPlante, Executive Assistant, handle the general management of the Bureau. This includes payroll and personnel, accounts payable and receivable, purchasing, travel arrangements and reimbursements, correspondence, receptionist duties, 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. The administrative staff handles more than $5 million in purchases and subcontracts each year.

Editing

The Editing staff, supervised by Chief Editor Susann V. Doenges, handle editing, word processing, desktop publishing, and proofreading of manuscripts for Bureau publications, contract reports, and other documents. They support the text-processing needs of the research staff and work closely with the Graphics section to produce publications that are made available to the public and to sponsors of Bureau research. During 1998, the staff prepared 12 Bureau publications and 62 contract reports. In addition, 54 papers and 67 abstracts by Bureau authors were published by professional journals and publishers.

Graphics

The Graphics section, under the direction of Graphics Manager Joel L. Lardon, is responsible for producing text illustrations and presentation materials, manual and digital photography, design and layout of Bureau publications and reports, as well as map design and finishing. In 1998, the Graphics section's 13-person full-time staff digitally produced 3 full-color plates, 3 black-and-white plates, 2,655 text illustrations, and 4,035 presentation graphics (35-mm slides, posters, and overhead transparencies).

All illustrations, including color and black-and-white plates, are produced entirely on computers. High standards are practiced to maintain the Bureau's reputation for quality. The Graphics section utilizes a 600-dpi black-and-white laser printer, a dye-sublimation color printer, one high-resolution large-format color desktop printer, a 300-dpi color ink-jet desktop printer, four 36-inch-wide color ink-jet printers, a 36-inch-wide hot laminator, two high-resolution film recorders, a 300-dpi monochrome scanner, and a high-resolution color scanner for opaque and transparent originals.

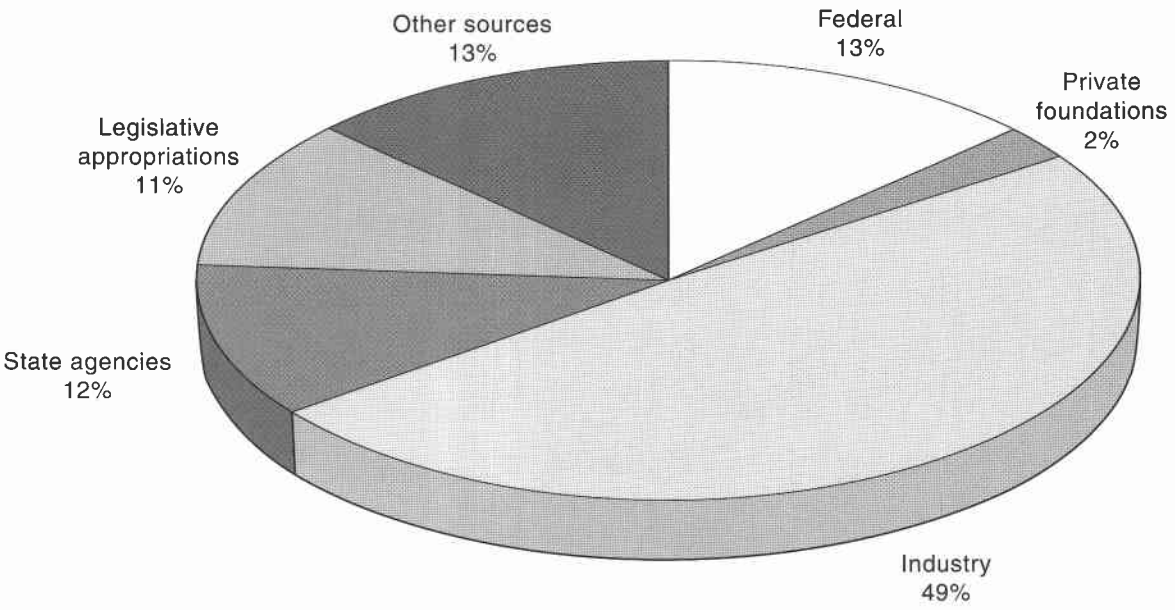
Information Technology Services

The Information Technology Services (ITS) section provides technical resources and services to Bureau scientists and support staff to assist research in interpretation, 3-D modeling, visualization, reservoir characterization, computer mapping, programming, data-base applications, and statistical and graphical analysis of data. ITS is responsible for systems and network design, as well as the purchasing, testing, installation, and training for these systems.

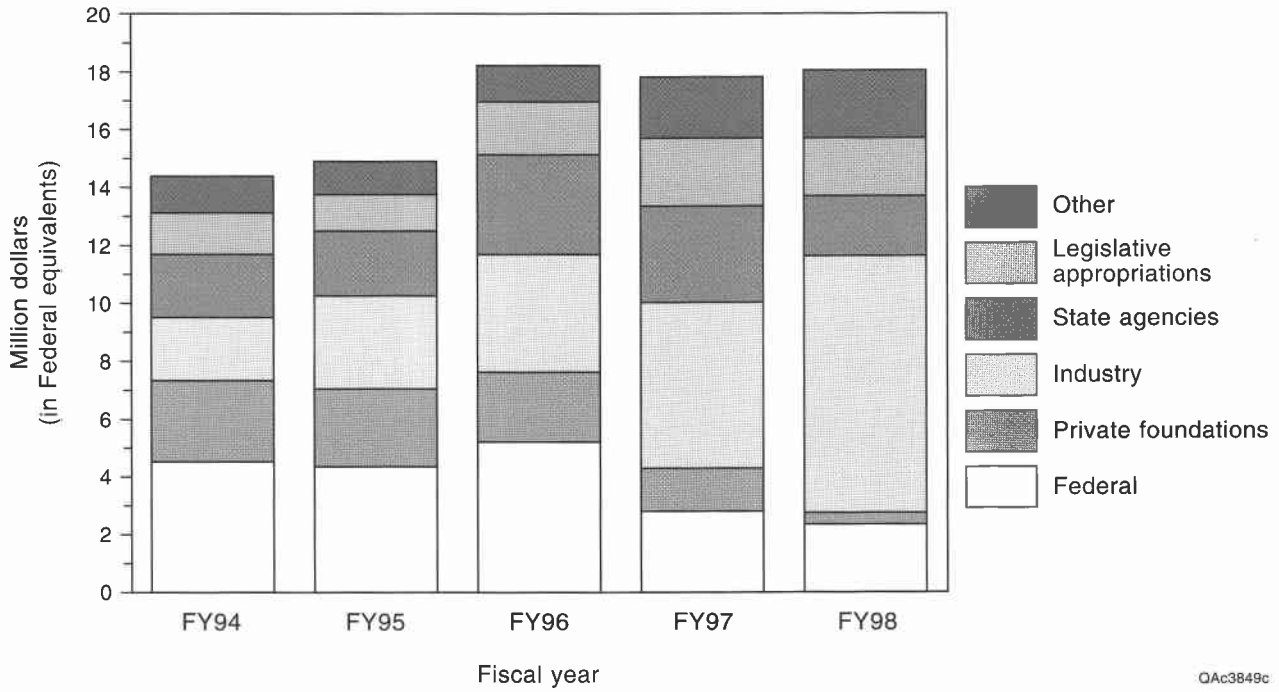
Services are provided by a state-of-the-art computing environment composed of Unix, VAX , Windows PC's and Macintosh computers, and support is provided by a full-time staff of six. The computing equipment is connected by a LAN within the Bureau and through a T-1 circuit to the university and the Internet. Print, file, E-mail, and application services are provided by various servers to the desktop across the 10/100 MB Ethernet LAN. A three-node VAX cluster provides VMS services. A total of 29 Unix workstations, 120 Macintoshes, and 107 Windows PC's make up the computing resources. Color-printing and plotting services are provided by a 36-inch Versatec electrostatic plotter, four HP 755-cm plotters, one LaserMaster ColorMark plotter, and four HP 1,600-cm printers. Additional hardware consists of 25 laser printers and 3 scanners. The university's IBM, Unix, VAX, and Cray computer systems are also available to Bureau researchers. Major geoscience software packages from Dynamic Graphics, ER Mapper, ESRI, Geomath, Green Mountain Software, GX Technology, Hampson-Russell, Landmark Graphics, Micro Seismic Technology, Neuralog, Paradigm Geophysical, Parallel Geoscience, PetCom Inc., PetroSoft, and Smedvig Technologies are installed on the appropriate platforms. Office-productivity software is installed on all desktops.

Sources of Funding and Budget Trends

FY 98 SOURCES OF FUNDING



FIVE-YEAR BUDGET TRENDS



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THE UNIVERSITY OF TEXAS AT AUSTIN
BUREAU OF ECONOMIC GEOLOGY
UNIVERSITY STATION, BOX X
AUSTIN, TEXAS 78713-8924

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