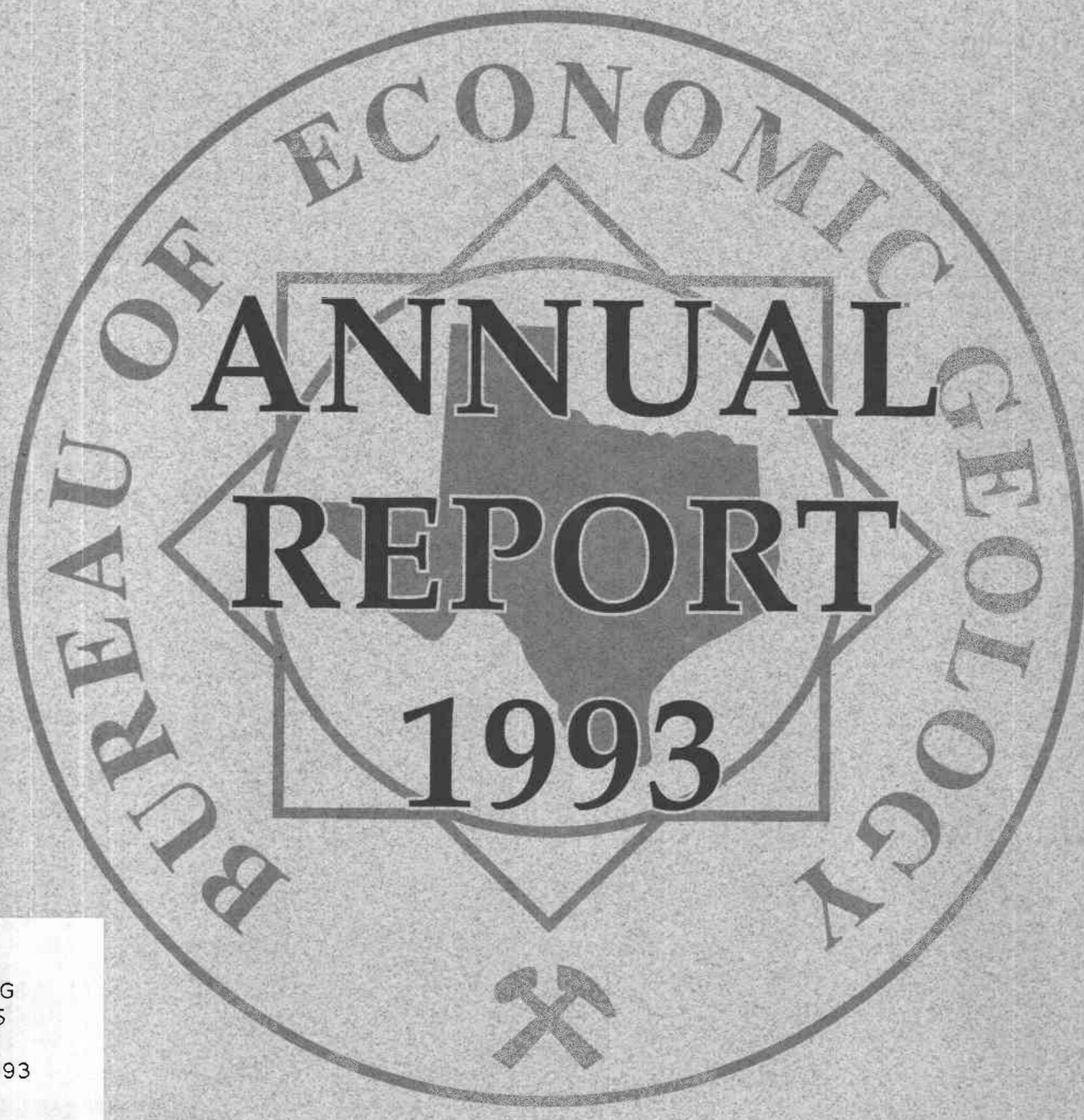

ANNUAL REPORT 1993

Bureau of Economic Geology

W. L. Fisher, Director • The University of Texas at Austin • Austin, Texas 78713-7508

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 entity of The University of Texas at Austin. It also functions as the State Geological Survey, a quasi-State agency, and the Bureau Director represents Texas in the Association of American State Geologists.

Extensive advisory, technical, and informational services relating to the resource
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programs in areas such as h
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conducted jointly with other ur
as well as with State, Federal,
The Texas Mining and Mineral
Institute is an administrative un

The Bureau provides ongoin
mental agencies including review

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
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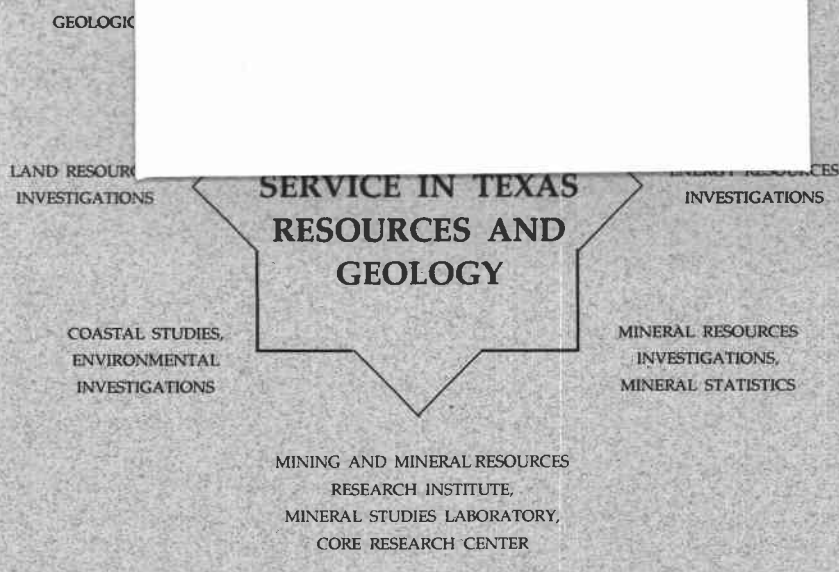

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Research

The operating budget of the Bureau of Economic Geology during 1993 totaled $13.6 million from line-item State appropriations and from 68 outside contracts and grants. Of these 68 funding sources, 25 were from interagency contracts with State and local governments and 12 were from the petroleum industry and private institutional foundations such as the Gas Research Institute (GRI). The rest were from various agencies of the Federal government, such as the U.S. Department of Energy (DOE), the U.S. Geological Survey, and the Minerals Management Service of the U.S. Department of the Interior.

In 1993, the Bureau conducted 54 research projects on geoscientific topics ranging from energy resources, waste isolation, hydrogeology, and experimental and applied tectonics, to coastal studies, mineral resources, and mapping. Eight new projects were initiated during the year. The new 1993 projects primarily involve energy-resource, ground-water–environmental, and coastal investigations, such as (1) determining the causes of, and possible solutions to, inefficient recovery of oil from the upper Paleozoic Tirrawarra Sandstone of the Cooper Basin, South Australia, (2) determining the capacity of the Edwards aquifer to store ground water in the San Antonio region of south-central Texas, and (3) defining the amount of water and sediment carried by the Trinity River, Texas, and the impact on ecologically important wetland habitats.

Several long-term projects of interest to the petroleum industry and to the Texas public were successfully concluded during 1993. The 4-year State Lands Energy Resources Optimization (SLERO) project, completed in August 1993, involved research by a team of geologists and engineers to recover more oil and gas from Texas State lands. Another Bureau study assessed the availability of ground water in Fayette and Colorado Counties and parts of adjacent counties by modeling aquifers in the Gulf coastal plain. The model provides a tool for assessing ground-water resources and for evaluating the benefits and impacts of alternative water-resource management strategies for counties near the Colorado River, south-central Texas. A recent inventory of nonfuel minerals in the Gulf of Mexico demonstrated that potentially economic deposits of sand, gravel, and heavy minerals occur on the Texas continental shelf. Particularly promising for future commercialization are nearshore deposits of sand for beach nourishment.

Most of the projects conducted by the Bureau during 1993 dealt with oil and gas investigations. The goal of the Bureau's continuing study of San Andres and Grayburg carbonate reservoirs is to develop new methods for understanding and predicting petrophysical rock properties in the subsurface that will help identify the distribution of oil remaining in the reservoirs after production. Long-term study of San Andres–Grayburg outcrops along the Algerita Escarpment and other areas of the Guadalupe Mountains has recently been expanded to include the nearby Brokeoff Mountains. Research will also encompass the South Cowden San Andres–Grayburg field in Ector County, Texas. Ongoing field and laboratory studies of two well-exposed fluvial-deltaic formations of western United States are designed to aid in improved oil and natural gas recovery from complex fluvial-deltaic reservoirs, specifically reservoirs of the Texas Gulf Coast, which account for 64 percent of total production from Gulf Coast reservoirs. The primary objective of an investigation of the Upper Cretaceous Ferron Sandstone of east-central Utah is to enable prediction of the distribution of gas-flow units and baffles and barriers to natural gas movement in gas reservoirs. Operators can thus optimize infill-drilling programs in prolific Gulf Coast gas fields. In a parallel study, the Lower Cretaceous Fall River Formation of eastern Wyoming and western South Dakota is being examined as an outcrop analog of subsurface fluvial-deltaic reservoirs in the nearby Powder River Basin. By contrasting geologic attributes of the two formations, a spectrum of data can be developed to predict facies architecture and permeability distribution of fluvial-deltaic deposits.

Several multiyear projects characterize the Bureau's research in natural gas. An ongoing Bureau program funded by GRI has three major components: (1) regional and reservoir-scale geologic study of the prolific but structurally complex Paleocene Wilcox Lobo gas trend of Webb and Zapata Counties, South Texas, (2) investigation of factors controlling gas production in the Upper Pennsylvanian Canyon Sandstone, Val Verde Basin, Texas, and (3) generic study of diagenetic controls on fracture occurrence and attributes based on data from GRI research wells in the Upper Cretaceous Frontier Formation of Wyoming, the Lower Cretaceous Travis Peak Formation of East Texas, and the Pennsylvanian Canyon Sandstone. Bureau geologists also conducted preliminary studies of the Pennsylvanian Cherokee Group of the Anadarko Basin, Oklahoma, and the Cambro-Ordovician Rose Run Formation of Ohio, where timely geologic and production-practice assessments were judged to be valuable. For the past several years, researchers assigned to the Secondary Natural Gas Recovery (SGR) project have been studying the impact of stratigraphic and diagenetic variation in fluvial-deltaic gas reservoirs in the Gulf Coast Basin and developing the necessary geologic and engineering knowledge to produce gas from these reservoirs efficiently. This phase of the SGR project, funded by GRI and DOE, was successfully completed in 1993. A new SGR project is concentrating on Pennsylvanian sandstone reservoirs in the Midcontinent region. The current research focus is the Atoka interval of Boonsville field in the Fort Worth Basin, North-Central Texas. During 1993, Bureau researchers finished studying geologic and hydrologic controls on production of coalbed methane in the Upper Cretaceous Williams Fork Formation and the Paleocene Fort Union Formation in the Sand Wash Basin of the Greater Green River Basin, Colorado and Wyoming.

Research has now expanded to other parts of the Greater Green River Basin.

The Bureau's Applied Geodynamics Laboratory (AGL) conducts mathematical and physical scale modeling to generate new concepts, test hypotheses, and duplicate specific geologic structures relevant to the location, origin, mechanics, and evolution of structural traps for oil and natural gas. Experimental research during 1993 examined a variety of gravity-driven tectonics focusing on diapirism, extension, contraction, and combinations of these structural styles. AGL researchers employed finite-element modeling of structural traps using GEOSIM-2D, a powerful computer program that simulates combinations of ductile and brittle deformation, large finite strains, faulting, sedimentation, and erosion. Field study of Upheaval Dome, Utah, continued in 1993. Exposures of the structure suggest that it may represent the pinched-off stem of a salt dome, a common feature in the productive fairways of the subsurface Gulf of Mexico. Upheaval Dome presents an opportunity to examine (in three dimensions at the surface) the brittle response to diapiric pinch-off.

In addition to energy-resource investigations, environmental and hydrogeologic investigations compose a large part of Bureau research. The Bureau continued a multiyear characterization of the overall geologic suitability of the proposed site for the Texas low-level radioactive waste repository in the Eagle Flat region of Hudspeth County, Texas. Studies centered on the vadose-zone processes in semiarid to arid settings, surficial geology, and neotectonics. In a new project, Bureau researchers are compiling an environmental atlas of the Rio Grande–Rio Bravo Border Area, a 100-km-wide strip straddling the United States–Mexico international border. The result will be a digitized map that will portray geologic, hydrologic, and natural resource information on the Border Area and that will be suitable for use with the Geographic Information System (GIS). Bureau researchers continued a 5-year hydrologic and geologic assessment of movement of ground-water contaminants in and around the Pantex Plant, the national site for assembling, maintaining, and disassembling nuclear weapons. Under the Bureau's leadership, scientists and engineers from several agencies will provide an integrated view of the geologic framework and hydrologic processes influencing (1) the rates and processes by which runoff is collected in playa basins and eventually recharged to the Ogallala aquifer, (2) the chemical evolution of contaminants as they pass through playa biota and underlying sediments, and (3) the hydrology and water chemistry of the Ogallala and perched aquifers. In 1993, as part of a remediation process designed to reduce salinity levels in the Canadian River and Lake Meredith, the primary sources of drinking water on the Texas High Plains, Bureau scientists used conductivity surveys (EM surveys) to locate saline ground-water plumes in alluvium and bedrock along a 150-km segment of the Canadian River valley upstream from Lake Meredith. Now that these saline-water sources have been identified, engineered remediation work is being planned.

Coastal studies conducted by the Bureau in 1993 addressed the complex problems surrounding natural and humanly-induced changes in sand-dominated Texas Gulf Coast shorelines and in the State's ecologically invaluable coastal wetlands. In a new project, Bureau coastal geologists are attempting to determine rates of sedimentation of the Trinity River that are necessary to maintain existing coastal wetland habitats in a setting experiencing a net rise in relative sea level. The primary objectives of a geological investigation of wind-tidal flats in Kenedy County, Texas, another new project in 1993, are to determine whether any significant surficial changes have occurred in the flats since the late 1800's and to investigate the geologic history of the area over the past few hundred years. In a 5-year study of coastal erosion and wetland loss from Sabine Pass to Sargent Beach, the Bureau is developing the information and expertise needed to ensure that future economic development of the coastal region will be compatible with the dynamics of the coastal system. Toward this end, Bureau researchers are providing technical data on coastal erosion and land loss to coastal planners, predicting future rates of erosion by natural and humanly-induced processes, evaluating the impact of relative sea-level rise on coastal lands and communities, and identifying offshore and nearshore sand resources for possible beach restoration. In a separate but related project, the Bureau provided technical assistance to identify the optimal zone for reestablishing and protecting fore-island dunes, updating recent maps of shoreline movement, and developing a program for monitoring the beaches and dunes of South Padre Island.

Further descriptions of these and other Bureau research projects follow.

Energy Resources Investigations

Petroleum

Reservoir Characterization Research Laboratory: Characterization of San Andres and Grayburg Reservoirs, West Texas and New Mexico

F. Jerry Lucia, principal investigator; Charles Kerans, Fred P. Wang, Stephen C. Ruppel, and Roger J. Barnaby; assisted by Andrew P. Czebieniak, Robin D. Dommisse, Gena B. Yung, Kirt A. Kempter, and Lisa E. Remington

The goal of the San Andres–Grayburg 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 geologic–petrophysical models for input into

reservoir simulators to improve predictions of reservoir performance and (2) mapping the distribution of remaining hydrocarbons. The research is funded by the RCRL Industrial Associates sponsors including Amoco, ARCO, BP, Exxon, Fina, JNOC, Oxy, Pennzoil, Phillips, Shell, Texaco, TOTAL, and UNOCAL. In addition, the program is supported by StrataModel, Radian, Halliburton, and Terra Science, companies that provide state-of-the-art software and seismic data.

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 to study the interwell environment both petrophysically and stratigraphically. Detailed stratigraphic and petrophysical models of the interwell environment can be developed from outcrop studies, and subsurface reservoir studies provide a means for developing the methods for applying this information to analogous reservoirs. Studies have focused on San Andres and Grayburg Formation reservoirs because of (1) the vast resource of remaining oil in these reservoirs and (2) the world-class outcrop of these formations in the Guadalupe Mountains, southeastern New Mexico.

Scaling factors are a key element of outcrop studies. A range of scales are considered, from regional sequence stratigraphy to depositional facies within individual genetic cycles. Petrophysical properties are examined on scales ranging from inches to thousands of feet laterally and inches to hundreds of feet vertically. The results indicate that (1) permeability structure within rock-fabric units is near random and petrophysical properties can be averaged for reservoir simulation input, (2) stacking patterns of rock-fabric units strongly affect production performance, (3) rock-fabric stacking patterns can be predicted within the sequence stratigraphic framework, and (4) the basic mapping interval is the genetic depositional cycle.

Subsurface studies focus on developing methods that allow permeability structure to be described in as much detail as it is in the outcrop models. A two-section study area in the Seminole San Andres Unit, Gaines County, Texas, has been the principal subsurface laboratory. Geological and petrophysical core and wireline log studies have demonstrated methods of (1) describing high-frequency sequence-stratigraphic framework, (2) relating rock fabrics to the stratigraphic framework and to petrophysical properties, and (3) calibrating wireline logs in terms of genetic depositional cycles, rock-fabric classes, and rock-fabric-specific permeability and saturations. Simulation studies have demonstrated the importance of (1) maintaining the stratigraphic and rock-fabric unit integrity, (2) inputting thin reservoir barriers to control vertical permeability, and (3) using rock-fabric-specific relative permeability curves. Using the geostatistical variography method of distributing permeability within the stratigraphic framework appears to have an insignificant impact on the simulation results, as opposed to using petrophysical data averaged over rock-fabric units.

The research program has recently expanded to include South Cowden San Andres–Grayburg field in Ector County, Texas, and a new outcrop analog area in the Brokeoff Mountains, Guadalupe Mountains, New Mexico. The goal is to use new methods to characterize flow and saturation properties of South Cowden field and determine, through reservoir simulation experiments, the location of remaining mobile oil. This information will be used to develop a program for recovering that oil.

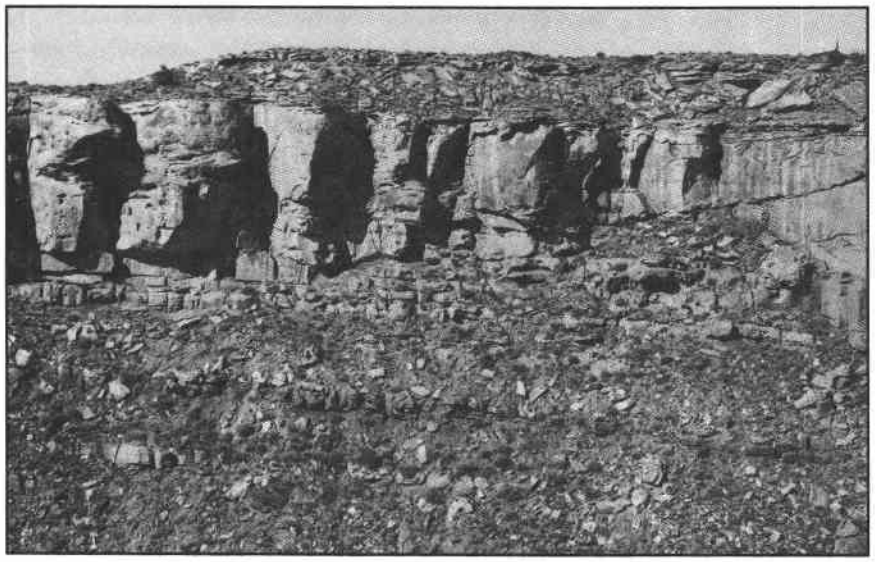
Quantification of Flow-Unit and Bounding Element Properties and Geometries, Ferron Sandstone, Utah: Implications for Heterogeneity in Gulf Coast Tertiary Deltaic Reservoirs

Noel Tyler and R. Stephen Fisher, principal investigators; Mark D. Barton; assisted by Edward S. Angle

Reservoir architecture, the product of depositional and diagenetic processes, governs migration paths during natural gas production. If we better understand the origin and history of the reservoir, therefore, we will be better able to predict paths of gas migration and more efficiently target remaining, conventionally recoverable natural gas that is prevented from migrating to the well bore by intrareservoir seals or bounding surfaces. Advanced recovery strategies that account for internal compartmentalization of the reservoir can be designed and implemented. Our study focused on outcrop analogs of fluvial-deltaic reservoirs because this reservoir class accounts for 64 percent of total production from Texas Gulf Coast reservoirs.

The major objectives of this work are to (1) investigate the geologic and petrographic factors that produce reservoir compartments (flow units) and bounding elements (seals) in sandstone reservoirs on the basis of outcrop characterization studies, (2) show that such information can be used to construct realistic reservoir models that can be used to test the effects of various infill drilling strategies, and (3) establish general principles for outcrop studies that can be used by other researchers. We selected the Ferron Sandstone outcrop as a reservoir analog because it is well exposed, the sequence stratigraphic setting is established, and the various Ferron genetic sequences were deposited in wave-modified to fluvially dominated deltaic settings that are analogous to major Gulf Coast gas reservoirs.

Deltaic sandstones extend 4 mi along sediment-transport direction in the landward-stepping Ferron genetic sequence GS5. Most sand was deposited in transgressive, delta-front, and distributary-channel facies. Distributary-channel sandstones constitute the principal reservoir facies; their mean permeability is approximately twice that of delta-front and transgressive sandstones. Channel architecture, bounding-surface character, and permeability distribution change systematically from landward to seaward in the system. Near the landward limit, mean permeability is 300 md, mud occurs as clasts along channel-flank bounding surfaces, and permeability systematically decreases upward. Near the seaward extent



Distributary channel-fill sandstone and bounding deltaic shales of the Ferron Sandstone, central Utah. Such outcrops enable investigation of the geologic and petrographic factors that produce flow units and seals in fluvial-deltaic sandstone reservoirs. Photograph by Noel Tyler.

of the system, mean permeability is 750 md, mud is segregated into discrete strata-bounding sand bodies, and vertical permeability trends are uniformly high.

Distributary-channel, mouth-bar, and delta-front deposits are volumetrically important in fluvially dominated Ferron sandstones of GS2. Distributary channels have good permeability but are narrow, sinuous, poorly connected to one another, and separated from underlying sandstones by low-permeability bounding surfaces. Distributary channels, therefore, would be difficult targets to develop. Mouth-bar facies are the best reservoir rock because they have moderate mean permeabilities and are laterally continuous at the between-well (320-acre) scale.

In both GS2 and GS5, variable preservation of lithofacies controls permeability distribution throughout the channel system. Semivariogram analysis shows that vertical and horizontal permeability correlation distances correspond to distances between bounding surfaces and to sand-body dimensions. Diagenetic overprint is minor, owing to low burial temperatures. We find a strong and predictable relation between macroforms, sedimentary facies, and permeability. We thus consider lithofacies and macroforms to be the fundamental architectural building blocks of both sandstones and sandstone reservoir models. Although permeability relations within lithofacies and macroforms are consistent throughout the facies tract, syndepositional erosion and truncation of earlier deposits significantly modify both preservation of lithofacies and macroforms and the resulting permeability structure.

These findings show that sandstone architecture differs distinctly from fluvially dominated (seaward-stepping) and wave-modified (landward-stepping) Ferron sandstones. Both outcrop and reservoir characterization studies must consequently be placed within a sequence stratigraphic framework that takes into account sandstone stacking patterns, the location of space for sediment deposition, and sediment preservation potential. Sandstone geometry and permeability patterns of the Ferron GS 2 at outcrop are similar to those of the Lake Creek G-2 and G-4 reservoirs (Wilcox Group, Texas Gulf Coast).

Maximization of Petroleum Recovery Efficiency in West Texas

Stephen C. Ruppel, principal investigator; Mark H. Holtz and Joseph S. Yeh; assisted by Ronald A. Johns and Robin D. Dommisse

Funded by the State of Texas under the Energy Research in Applications Program, this project, which was completed in August of 1993, was designed to develop new strategies for recovering remaining hydrocarbon resources in existing, low-recovery-efficiency reservoirs. Specifically targeted were restricted platform carbonate reservoirs in the Permian Basin, which exhibit recovery efficiencies that are nearly half the average of those for other carbonate reservoirs. Monahans Clear Fork (Lower Permian) field in West Texas, typical of this group of reservoirs, was selected for detailed, multidisciplinary study by a consortium of more than 30 principal scientists and engineers from four major universities in the state (The University of Texas at Austin, University of Houston, Texas A&M University, and Texas Tech University).

Bureau research on the project primarily aimed at developing a more sophisticated approach to defining depositional and diagenetic facies architecture in order to model reservoir petrophysics and flow unit architecture more accurately. A key finding of this research is that multifrequency rise–fall sea-level cycles strongly affect development of depositional facies, diagenesis, and porosity. Vertical facies stacking patterns result directly from composite changes in accommodation produced by the interaction of three scales of cyclicity. Lateral facies changes are a function of the combined effects of cyclicity and paleotopography. Porosity development is punctuated by intermediate-scale cyclicity due to the effects of early diagenesis during sea-level fall. Because it primarily results from diagenesis at cycle tops, porosity does not directly indicate permeability. Permeability development is largely restricted to grain-dominated subtidal rocks, primarily where these rocks have de-

veloped at cycle tops and have thus been subjected to diagenesis. Whereas porosity is also well developed in tidal-flat rocks, permeability is virtually absent because mud-dominated rock fabric is typically encountered in these rocks.

Flow units were defined by constructing a sequence stratigraphic reservoir model that identifies intermediate-scale cyclicity and the distribution of grain-dominated subtidal rocks. This was done using cores and spectral gamma-ray wireline logs. The latter proved crucial to recognizing the distribution of porous, but nonpermeable, tidal-flat rocks, as well as permeable subtidal rocks. The facies architecture was used as the basis for developing fieldwide, three-dimensional models of porosity, permeability, and water saturation using StrataModel Stratigraphic Geocellular Modeling software. These models, which utilized approximately 160 wells and a cell size of 2 ft × 100 ft (1.5 million cells), were in turn used to calculate reservoir volumetrics.

Analysis and reconnaissance study of other Clear Fork reservoirs on the Central Basin Platform in West Texas indicate that approaches to improved geological and petrophysical characterization developed and employed in the Monahans reservoir can apply to most reservoirs of this type. These techniques should form a strong basis for enhanced recovery of the sizable remaining hydrocarbon in these rocks.

State Lands Energy Resources Optimization (SLERO) Project

Noel Tyler, director; R. P. Major, consortium principal investigator; Roger J. Barnaby, Kenneth T. Barrow, Don G. Bebout, Michael H. Gardner, Chester M. Garrett, Jr., Douglas S. Hamilton, Claude R. Hocott, Mark H. Holtz, Paul R. Knox, Thomas A. Tremblay, and Joseph S. Yeh; assisted by Nina L. Baghai, Dieter K. Beike, Radu Boghici, Chun-Yen Chang, Douglas C. Dawson, Herbert Haubold, Shing-Tzong Lin, Ning Li, Amy K. Sapp, Mohammad A. Sattar, Huade Yang, and Hongliu Zeng

Project SLERO was a 4-year, five-university consortium study that was completed in August 1993. The Bureau of Economic Geology served as lead contractor of a multidisciplinary team of scientists and engineers, including geologists, geophysicists, and petroleum engineers from The University of Texas at Austin, Texas A&M University, The University of Houston, Texas Tech University, and Lamar University. The project consisted of integrated research designed to increase hydrocarbon recovery from existing Texas State Lands reservoirs. It was funded by the Office of the Governor of Texas and was conducted in cooperation with the Texas General Land Office. Activities within this consortium study were divided into (1) play analysis and resource assessment, (2) reservoir characterization, and (3) advanced extraction technology.

Play Analysis and Resource Assessment

The play context was used to identify individual fields for site-specific reservoir characterization and to establish key reservoir engineering parameters for resource assessment. Each geologically based play has characteristic engineering parameters, such as porosity, permeability, saturation, and pressure, which, along with cumulative production and field size, were used to calculate original oil in place, remaining mobile oil, and residual oil in all major State Lands reservoirs.

Texas State Lands contain 380 oil reservoirs and 547 gas reservoirs that have a cumulative production of more than 1 million barrels of oil equivalent. Our estimates indicate that 1.6 to 1.8 million stock tank barrels (MMSTB) of mobile oil, 2.1 to 2.3 MMSTB of residual oil, and 6.4 trillion cubic feet of gas remain in these reservoirs.

Reservoir Characterization

The second phase of this study, reservoir characterization, involved detailed site-specific studies of reservoirs that were identified by play analysis as representing a larger group of State Lands reservoirs. The object was to define styles of internal reservoir architecture and heterogeneity and to design recovery-efficiency strategies that may be applied to all representative reservoirs. Ten individual reservoirs and two major reservoir-bearing formations were selected for detailed study.

Site-specific study areas ranged from Miocene reservoirs of the Gulf Coast in South Texas to Permian reservoirs of the Permian Basin in West Texas. In South Texas, study of Powderhorn field in Calhoun County, which produces from a Miocene barrier/strandplain reservoir, resulted in siting an infill well that made a deeper pay discovery and added at least 750,000 bbl of oil and an unknown amount of gas to field reserves. Investigations of three fields that produce from multiple barrier/strandplain reservoirs of the Oligocene Frio Formation, Lavaca Bay (Calhoun County), Red Fish Bay (Nueces County), and West Fulton Beach (Aransas County) fields, identified numerous infill well locations and recompletion opportunities to target extensive remaining reserves in these reservoirs. At Seventy-Six West field in Duval County, which produces from an Eocene barrier/strandplain reservoir in the Jackson–Yegua trend, our research identified an area of approximately 150 ac in the south part of the field that is now proven to be oil productive but that had not been previously drilled. A regional study of Duval County Ranch, the area surrounding Seventy-Six West field, identified several exploration targets in potential reservoirs that range in age from Paleocene through Eocene.

Significant untapped gas reserves were found in Las Tiendas field in Webb County, where the low permeability of a Cretaceous deltaic sandstone reservoir presents opportunities for infill drilling at a closer well spacing. Alabama Ferry field in Leon County produces oil from a stacked group of Cretaceous carbonate grainstone bars. Early waterflood breakthrough can be corrected by plugging the high-permeability "thief zones" identified by our study, which will significantly increase ultimate total recovery from this reservoir.

At Keystone (Colby) field in Winkler County in the Permian Basin, which produces from multiply stacked

sandstones deposited in a peritidal shelf environment, we estimate that 15 MMSTB of mobile oil has not been accessed by existing well bores. This presents numerous infill-drilling and recompletion opportunities. A regional study of Delaware Mountain Group sandstones in the Delaware Basin demonstrated that hydrocarbon production is controlled primarily by the distribution of reservoir seals, which is controlled by predictable and mappable depositional cycles. A site-specific study of one Delaware Mountain Group field, Screw Bean field in Reeves County, identified numerous infill drilling and recompletion opportunities. Study of the Keystone (San Andres) reservoir, a dolomitized platform carbonate reservoir in the Permian Basin, resulted in siting an infill well that tested at a flow rate of more than 150 bpd, which was the most productive well in that reservoir since initial development in the 1960's.

In addition to identifying site specific opportunities for increased production in State Lands oil and gas fields, SLERO researchers have received accolades from their science and engineering peers for technical publications that have resulted from this project. Among numerous papers, abstracts, theses, and dissertations, six publications that resulted from SLERO research have won best paper awards.

Advanced Extraction Technology

The final phase of the project, advanced extraction technology, involved using the results of both play analysis and reservoir characterization to identify groups of State Lands reservoirs that will respond to specific development techniques. These techniques included waterflood and carbon dioxide flood design, surfactant flood experiments, cyclic carbon dioxide injection design, and development of methods to evaluate the effectiveness of hydraulic fracture stimulation. These advanced extraction technologies, aimed at production problems encountered in State Lands reservoirs, are designed to maximize ultimate oil and gas recovery.

Revitalizing a Mature Oil Play: Strategies for Finding and Producing Unrecovered Oil in Frio Fluvial-Deltaic Reservoirs of South Texas

Noel Tyler and Robert J. Finley, principal investigators; Lee E. McRae, Mark H. Holtz, and Paul R. Knox; assisted by Chun-Yen Chang, Shannon L. Crum, Douglas C. Dawson, and Mohammad A. Sattar

Fields in the mature Frio Fluvial-Deltaic Sandstone oil play of South Texas have already produced nearly 1 Bbbl of oil yet still contain more than 1.6 Bbbl of unrecovered mobile oil and nearly the same amount of residual oil resources. More than half of the reservoirs in this play have already been abandoned, and large volumes of oil may remain unproduced unless advanced characterization techniques are applied to define untapped, incompletely drained, and new pool reservoirs as suitable targets for near-term recovery methods.

The Bureau of Economic Geology has entered into a 46-month cost-shared cooperative agreement with the U.S. Department of Energy (DOE) to develop strategies to maximize the economic producibility of oil reservoirs in fields within this mature oil play. This project is one of several recently selected by the DOE under its new targeted field Oil Recovery Technology Program, whose primary goal is to forestall premature abandonment by extending the economic life of some of the nation's most endangered crude oil reservoirs. Fluvial-deltaic reservoirs represent a large percentage of reservoirs on the verge of being abandoned, despite having large amounts of remaining oil. The stratigraphically complex fluvial-deltaic reservoirs in the Frio Formation of the South Texas Gulf Coast provide excellent candidates for studying and characterizing the details of stratigraphic heterogeneity inherent in fluvial-deltaic depositional systems.

Primary objectives of this project are to develop interwell-scale geological facies models of Frio fluvial-deltaic reservoirs and combine them with engineering assessments and geophysical evaluations to characterize reservoir architecture and flow unit boundaries and to determine the controls that these characteristics exert on the location and volume of unrecovered mobile and residual oil. These results will lead to identifying specific opportunities to exploit these heterogeneous reservoirs for incremental recovery by recompletion and strategic infill drilling.

Research conducted so far on the project has included an intensive screening and statistical analysis of reservoir data from fields throughout the play in South Texas. Two fields having active reservoirs and extensive production and geologic data bases have been chosen for detailed characterization studies, Rincon field in Starr County and western T-C-B field in Jim Wells County. Each field contains a 2,000-ft-thick productive interval within the middle and lower Frio that consists of multiply stacked, lenticular, distributary-channel and delta-front sandstone reservoirs interbedded with nonreservoir prodelta and delta-plain mudstones.

Production data were compiled and core data were analyzed by reservoir in order to establish completion densities and characteristics of individual reservoir zones. These criteria, along with reservoir resource estimates, will provide the basis for selecting reservoirs having the greatest additional resource potential in order to focus detailed characterization studies.

Characterization and Recovery Optimization of Braid-Delta Reservoirs, Tirrawarra Field, South Australia

Noel Tyler, principal investigator; H. Scott Hamlin, Robert J. Seggie, Shirley P. Dutton, Bob A. Hardage, Peter Lansom, and Joseph S. Yeh; assisted by Eugene M. Kim, John M. Mendenhall, Virginia M. Pendleton, and Robert S. Single

The purpose of this 7-month study, which was funded by Santos Ltd., an Australia-based oil company, was to increase reserves and ensure sustained production from the Tirrawarra Sandstone reservoir over the mid- to long term. Although the resource base exceeds 150 MMbbl of oil, recovery efficiency has been less than 11 percent, and previous geological modeling has proved unsatisfactory for enhancing reservoir performance. During this study,

BEG and Santos researchers collaborated to develop an integrated geologic and engineering description of the reservoir, which was deposited during the Late Carboniferous and Early Permian in a glacially influenced fluvial-lacustrine depositional system. Detailed field-scale characterization of the component facies of this depositional system proved to be the key to understanding past reservoir performance and to successfully identifying the volume and residency of the remaining oil in place.

A broad, well-organized data base allowed full integration of all aspects of this multidisciplinary study. The available data from this 73-well field included 3,000 ft of whole core from 29 wells, modern well log suites, a dense two-dimensional seismic grid, and abundant petrophysical and well-test data. The thrust of the project involved (1) genetic stratigraphic analysis of the Tirrawarra reservoir interval and (2) synthesis of core, well log, and petrophysical data to identify, quantify, and map facies-based reservoir flow units. The reservoir interval is 100 ft thick and comprises four facies assemblages subdivided into six flow units on the basis of stratigraphic position and fluid-transmission properties. The reservoir interval formed when a braid-delta system prograded into a lacustrine basin, and the main reservoir facies are bed-load channel-fill sandstones and conglomerates. Depositional environment was shown to be the primary control on reservoir properties and productivity.

Results from geological and engineering studies were synthesized in a three-dimensional model that led to substantial reserve growth and development of strategies for incremental recovery. Detailed stratigraphic cross sections and contour maps established flow-unit architecture and delineated flow barriers within and between flow units. Whereas petrographic analysis of thin section data documented the diagenetic fabric of each flow unit, petrophysical analysis of log and core data quantified flow-unit-specific properties, such as porosity and permeability distribution, water saturation, and net pay. Geophysical interpretation of seismic data then established the structural framework of the field. Finally, engineering analysis of volumetrics and production patterns determined remaining oil in each flow unit and confirmed the validity of the facies-based reservoir model. The project was successfully completed in a technology transfer workshop presented to Santos and its Tirrawarra field unit partners in Adelaide, South Australia.

Oil and Gas Resource Atlas Series: Offshore Northern Gulf of Mexico

Robert J. Finley, principal investigator; Don G. Bebout, Robert A. Morton, Steven J. Seni, Bruce A. Desselle, and Allan R. Standen; assisted by Denise H. Ketcham, Todd J. Minehardt, Ravi V. Nigudkar; subcontracts to Louisiana State University Center for Coastal, Energy, and Environmental Resources, and to Alabama Geological Survey

In collaboration with other State geological surveys, the Bureau of Economic Geology (BEG) is currently developing a series of oil and gas atlases that are supported by GRI, DOE, and MMS. In the fall of 1992 and the spring of 1993 the DOE and GRI funded BEG to produce an atlas series of oil and gas reservoirs in the Federal and State offshore waters of the northern Gulf of Mexico. During the first year of a 4-year program we have concentrated on collecting geologic and engineering data from the offshore Texas area. An Industrial Technical Advisory Group was established to aid the program and currently includes ARCO Oil and Gas Company, Conoco, Inc., Marathon Oil Company, Oryx Energy Company, Shell Offshore, Inc., Texaco USA, and UNOCAL, Inc.

The decline in domestic oil and gas production and the increase in dependence on imports of foreign crude oil highlight the need for an integrated analysis of domestic oil and gas resources. The lower 48 states have shifted exploration emphasis from exploring frontier areas to extending development in mature hydrocarbon provinces. The northern Gulf of Mexico region is an especially attractive exploration area because of its rich hydrocarbon endowment, its modern petrochemical production and refining infrastructure, and its untapped potential. Systematically synthesizing geologic and engineering data on oil and gas resources reservoir by reservoir within each play is required for successful exploration and development of the offshore northern Gulf area to continue. The Gulf of Mexico offshore region contains an estimated 17 and 26 percent, respectively, of the nation's undiscovered conventional oil and gas resources. In Federal waters alone, more than 19,000 reservoirs in at least 702 active fields have produced an estimated 7.8 Bbbl of oil and about 89 Tcf of gas.

The northern Gulf of Mexico is currently receiving much attention from the oil and gas industry for both extending fields and infill drilling in mature areas of the basin. Development drilling activity increased by 39 percent (over the same period last year) in the first quarter of 1993. In addition, exploration drilling has increased 91 percent from the first-quarter 1992 levels. Major new petroleum discoveries in the 200- to 500-MMbbl-field-size class represent a brand-new hydrocarbon play that is associated with horizontal salt features in deeper waters across the outer shelf and slope.

Systematic compilation of Gulf of Mexico reserves and production data within a reservoir play-defined framework will help assess the most important combinations of trap types and producing facies. The data can be used (1) to identify areas of greatest potential, having the highest concentration of remaining unrecovered hydrocarbons in existing fields and (2) to guide frontier exploration in ultradeep water on the basis of analysis of older submarine fans and slope-apron plays encountered beneath the shallower adjacent continental shelf. Regional reservoir play analysis thus provides a logical basis for simultaneously evaluating both field reserve growth potential and opportunities for extension exploration in mature plays. In addition, synthesis of oil and gas reservoirs will contribute to a better understanding of the history of the Gulf Coast Basin and will lead to better predictive capabilities with regard to future exploration and development opportunities in the basin.

Internal Geometry of a Modern Carbonate Grainstone Shoal: Joulters Cays Ooid Shoal, Bahamas

Don G. Bebout, principal investigator; Richard P. Major and Paul M. Harris (Chevron Petroleum Technology Company)

For the past 10 years the need for more detailed information on producing reservoirs has been escalating as operators seek to recover the hydrocarbons from geologically complex reservoirs more efficiently. Reservoir and outcrop studies at the Bureau of Economic Geology have underscored the importance of three-dimensional internal variations in textures and structures of grainstone bodies as the controlling influence on oil recovery in many carbonate reservoirs. Modern grain bars offer the opportunity to characterize the style of heterogeneity in these systems and, in addition, provide the option for observing surface marine processes that were responsible for their genesis.

The Joulters Cays ooid shoal and associated environments, north of Andros Island, Great Bahama Bank, were selected as an outstanding example of a wave/storm-dominated marine sand belt. The initial study, which was conducted in September 1989, focused on a detailed investigation of a 1-mi^2, reservoir-scale part of the ooid shoal. The objective of this study was to document textural and early diagenetic variations within the upper grain-dominated part of the upward-shoaling sequence at a scale unmatched by previous studies of modern carbonate depositional environments but equivalent to studies of heterogeneities documented in ancient reservoirs.

The goal of the short return to Joulters Cays in early 1993 was to document alteration of the surface configuration of the shoal complex by Hurricane Andrew, which passed just to the north of Joulters in August 1992. Prominent washover bars were planed off and well-sorted ooid facies were deposited in low areas on the shoal where poorly sorted and muddy ooids previously accumulated. Thus, this single, short-term depositional event contributed significantly to the internal heterogeneity of a shoal complex typical of that preserved as ancient grainstone reservoirs.

Evolution of Earth's Early Atmosphere: Evidence from Earliest Proterozoic Platform Carbonates

Noel Tyler, principal investigator; Richard P. Major and Roger Tyler; assisted by Norman G. Van Broekhoven

The Early Proterozoic witnessed a remarkable change in the composition of the Earth's primitive atmosphere. Ancient (Archean) Earth history was dominated by magmatic activity, which produced an atmosphere dominated by carbon dioxide, methane, ammonia, and sulfur dioxide. During the Early Proterozoic, oxygen released by cyanobacterial photosynthesis profoundly changed the atmospheric composition from anoxygenic to oxygenic, which altered mineral stabilities and created conditions optimal for evolving complex life forms.

The Bureau of Economic Geology, under funding from the Texas Higher Education Coordinating Board's Advanced Research Program, has initiated a petrographic and geochemical study of Proterozoic carbonate rocks from the eastern Transvaal of South Africa. The purposes of this study are to track the nature of change in the composition of the atmosphere and to identify the effects of this major change in the ocean–atmosphere system on the precipitation of marine carbonate sediments. These carbonate rocks are examples of primary dolomite precipitation, that is, carbonates having the composition $CaMg(CO_3)_2$. Most younger dolomites are the product of altered calcite or aragonite sediments or rocks. The carbonate rocks of the eastern Transvaal thus provide a unique opportunity to study these phenomena because they are among the earliest examples of marine dolomite sediments that have not been severely deformed by tectonism or, as is the case for many Precambrian rocks, subjected to substantial hydrothermal alteration or metamorphic temperatures and pressures.

Approximately 250 dolomite and chert samples collected from the Malmani Dolomite of the Proterozoic (2.4 to 2.2 billion years old) Chuniespoort Group in the Eastern Transvaal Province of South Africa have been described in hand specimen and archived. These samples, collected during a 6-week field excursion, include samples collected from cores made available to this study by Rand Mines, Ltd. Approximately 50 rock samples were taken from within the metamorphic aureole of the Bushveld intrusive igneous complex. After thin-section preparation, preliminary microscopic examination indicates that rock samples taken close to the Bushveld complex contain several minerals normally unassociated with sedimentary environments. The presence of these minerals near the Bushveld complex will be incorporated into our interpretations of the chemical composition. Powder extracts from more than 90 samples have been prepared and these powders are currently being analyzed for mineralogy by X-ray diffractometry, cation composition by inductively coupled mass spectrometry, and anion isotope composition by gas mass spectrometry.

Advanced Exploration and Development Research for Revitalizing Hydrocarbon Recovery in the Permian Basin, West Texas

Noel Tyler, principal investigator; Richard P. Major, Kenneth T. Barrow, and Douglas B. Swift; assisted by Qing Fang, Alexander P. Schoellkopf, and Joseph C. Fiduk

More than 1,600 large (>1 MMboe) oil and gas fields containing an estimated 5.4 Bboe are thought to lie in the Permian Basin awaiting discovery. Most of these reservoirs will be found in subtle traps by exploration geologists who understand the complex interrelationships among hydrocarbon generation and migration, diagenesis, and trap formation. This 3-year project, funded by the Advanced Technology Program of the Texas Higher Education Coordinating Board, will produce an

integrated analysis documenting the origin, migration, and entrapment of hydrocarbons within the Paleozoic structural and depositional framework of the Delaware Basin and its margins. This study emphasizes the pre- and syndeformational deposits of Ordovician through Early Permian age. Older seismic data have been reprocessed and interpreted at The University of Texas of the Permian Basin. Geologic and geophysical interpretation and project synthesis are under way at the Bureau of Economic Geology.

The Delaware Basin is a late Paleozoic foreland basin that formed in response to compressional stress transmitted to the craton during emplacement of the Ouachita–Marathon allochthon. Subsidence of the basin began in the Late Mississippian, accelerated rapidly in the Early Pennsylvanian (Atokan), and culminated during the Early Permian (Wolfcampian). Generation and migration of hydrocarbons from early and middle Paleozoic source rocks began in the center of the basin during rapid burial in the Pennsylvanian and continued through the Permian. Most of the known producing structures in the basin were formed during this late Paleozoic compressional event.

This study addresses questions relating to the complex history of the Delaware Basin. As many as a dozen different source rocks, ranging in age from Ordovician to Permian, have been identified in the basin. An understanding of the timing of hydrocarbon generation and migration relative to the timing of trap and seal formation will help explain current patterns of petroleum accumulation. Because most of the larger existing fields producing from pre-Permian strata are structurally trapped, deep exploration programs have traditionally targeted seismically imaged structures. Understanding the spatial and temporal distribution of migration pathways will enable exploration geologists to formulate new plays in their search for the subtle stratigraphic traps that will be tomorrow's significant discoveries in this mature province.

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

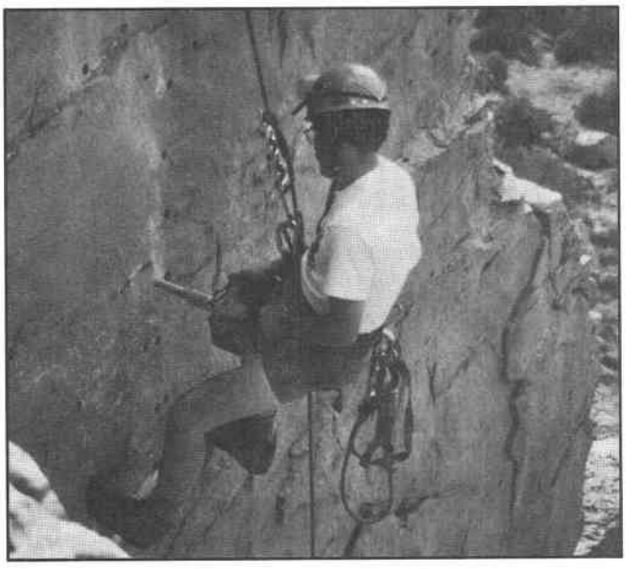
Shirley P. Dutton and Noel Tyler, principal investigators; Michael H. Gardner and Brian J. Willis; assisted by Mary C. Crabaugh, Widya Dharmasamadhi, Sam A. Epstein, Senira S. Kattah, and Ciarran J. O'Byrne

The Bureau of Economic Geology (BEG) has completed the first year of a research project aimed at reservoir characterization of fluvio-deltaic depositional systems. Our approach is to quantify the interrelationships among sequence stratigraphy (including stacking patterns, genetic arrangement, and chronostratigraphic framework), depositional architecture, diagenetic history, and the petrophysical parameters of permeability, porosity, and saturation through detailed outcrop characterization. Sand-body geometry and permeability data collected from outcrop form the basis for constructing reservoir models and flow simulation.

This study builds on the results of work that was conducted by BEG on the Ferron Sandstone in Utah, a fluvio-deltaic depositional system that was deposited in a high accommodation setting. The Industrial Associates consortium was formed to study fluvio-deltaic strata from a low accommodation setting and thus develop a spectrum of data that can be used to predict facies architecture and permeability distribution in any accommodation setting. Key to this effort are the predictive capabilities of sequence stratigraphy. A chronostratigraphic framework provides a context in which facies architecture may be evaluated and related to the spatial structure of heterogeneity.

The Lower Cretaceous Fall River Formation in the Black Hills of eastern Wyoming and western South Dakota was chosen as the initial focus of the project. The Fall River, a delta and incised-valley system that was deposited in a low accommodation setting, has excellent outcrop exposures for permeability mapping. Furthermore, extensive sets of cores and reservoir production data are available from Buck Draw field, which produces from the Fall River Formation in the nearby Powder River Basin. The project thus has an excellent opportunity to test the portability of high-resolution outcrop characterization to the subsurface.

The regional sequence stratigraphic framework of the Fall River was established during field work completed



Bureau scientist collects rock plugs from stacked channel sandstones of a valley-fill complex, Cretaceous Fall River Formation, western South Dakota. Petrophysical analysis of rock samples facilitates high-resolution quantification of permeability structure in these exposures, which form reservoirs in the nearby Powder River Basin. Photograph by Brian J. Willis.

in the summer of 1993. The Fall River represents a storm- and tidally modified deltaic depositional system that was substantially modified by fluvial systems that incised and cannibalized preceding deposits in response to low accommodation conditions. In this low accommodation setting, the Fall River Formation is characterized by thin, attenuated, and laterally persistent shallow-marine facies tracts that are areally extensive and regionally correlated. The valley-fill facies tracts occupy deep and narrow (75 to 130 ft deep and 1 to 4 mi wide) valleys. The valley-fill facies tract changes vertically from multistory transverse barforms of low-sinuosity, bedload-dominated fluvial systems to estuarine-channel facies.

Detailed architectural mapping and outcrop quantification of permeability structure in Fall River valley-fill deposits were also conducted during the summer of 1993. This work was done in an area that had good three-dimensional exposures, where valley-fill facies tracts of several Fall River sequences are merged and form a setting similar to that of Buck Draw field. Diagenetic studies are under way to investigate differences in diagenetic history between the Fall River in outcrop and in the subsurface, in order to test the portability of outcrop permeability structure to the subsurface.

This investigation is funded by a consortium of industrial associates comprising the following companies: Amoco Production Company, BP Exploration Operating Company Limited, Chevron Oil Field Research Company, Conoco, Inc., Société Nationale Elf Aquitaine (Production), Exxon Production Research Company, Intevep S. A., Japan National Oil Company, Kerr-McGee Corporation, The Louisiana Land and Exploration Company, Mobil Research and Development Corporation, Occidental International Exploration and Production, Inc., OXY USA, Inc., Oryx Energy Company, STATOIL, and Union Oil Company of California.

Characterization of Eocene Reservoirs: LL-652 Area, Lake Maracaibo, Venezuela

Noel Tyler, principal investigator; Eulise R. Ferrer, William A. Ambrose, Shirley P. Dutton, Joseph S. Yeh, Fred P. Wang, Hongliu Zeng, and H. Scott Hamlin; assisted by Pedro J. Gamboa, Mohan I. Javalagi, Senira S. Kattah, Ronald A. Johns, and Amy K. Sapp

The goal of this 16-month project, funded by Lagoven S. A., an affiliate of Petroleos de Venezuela S. A., is to maximize oil recovery from 10 lower Eocene reservoirs in the C Members of the Misoa Formation in Lagunillas field, northeastern Lake Maracaibo. These structurally complex deltaic reservoirs have produced 135 MMbbl of oil for a recovery efficiency of 22 percent and contain considerable volumes of unrecovered mobile oil at a current well spacing of approximately 80 acres. The Bureau of Economic Geology, in collaboration with Lagoven, conducted an integrated study of Lagunillas field that included a structural, stratigraphic, petrophysical, and production engineering analysis from well logs, cores, seismic, thin-section, and petroleum engineering data. The objectives of this study were to define (1) reservoir limits, (2) characteristics of rocks, reservoirs, and fluids, (3) volumes of oil originally in place, (4) hydrocarbon recovery factors, (5) recoverable oil reserves through primary production methods, and (6) volumetrics and potential for additional recovery.

The structural and stratigraphic framework of the 4,000-ft-thick reservoir section was established using a grid of cross sections that intersect more than 150 wells. Sandstones and shale beds in the most productive intervals in the Lower Eocene (C-3-X and C-4-X Members) were carefully correlated to document the depositional geometry and lateral continuity of reservoir sandstones. Detailed descriptions of more than 3,000 ft of core from the C-3-X through C-7-X Members were incorporated into the cross sections to interpret environments of deposition. These cores contain a variety of sandstone-rich channel deposits of good reservoir quality, which merge seaward (northeastward) into nearshore-marine (delta-front) sandstones of intermediate reservoir quality. As a result of the tidally influenced deltaic depositional system, sand-body trends in Lagunillas field are strongly linear and are consistently oriented northeastward, parallel to depositional dip. These sandstone trends impart a preferred pathway for fluid flow in the reservoir. The sandstone bodies are narrow, typically less than the distance between wells (2,000 ft), and are bounded laterally by low-permeability siltstones and mudstones, resulting in laterally discontinuous and compartmentalized reservoirs.

The volume of oil remaining in each submember of the C reservoirs was determined from volumetric analysis and petrophysical evaluation of several key wells. Incompletely drained areas of the reservoirs targeted for development occur where narrow, dip-elongate distributary-channel and tidal-ridge sandstones are compartmentalized by faults. Development strategies to recover the remaining oil resource will include infill drilling, recompletions, and secondary recovery. As a result of volumetric analysis, the existing reserves have been tentatively increased by 113 percent from 120 MMbbl to 247 MMbbl, and 28 geologically targeted infill wells and field extension locations have been identified.

Technology Transfer

Bob A. Hardage and William L. Fisher, principal investigators; Sigrid J. Clift, Robert J. Finley, and Noel Tyler

During 1992, the Bureau of Economic Geology (BEG) organized, managed, and participated in an active program of transferring new technology into the daily operations of Texas-based independent oil and gas operators. The Texas Independent Producers and Royalty Owners (TIPRO) office organized several meetings between Bureau staff and independent operator groups

across the state, and on the basis of discussions with these operators, BEG prepared a prioritized list of the technical assistance most needed by Texas independent producers. The technical areas for which Texas independents most commonly requested education included 3-D seismic technology, modern petrophysical techniques, well completion and testing strategies, and geological concepts required for accurate reservoir characterization. Experts from within and outside the Bureau were then recruited to prepare training classes on these topics as well as several other high-priority subjects, and seven training schools were held at different locations across the state. Approximately 600 independent operators attended these technology transfer classes.

Conodont Chemostratigraphy: Improvements in the Geologic Time Scale

Stephen C. Ruppel, principal investigator; Eric W. James; assisted by Nikolas A. Hazel and Treavor A. Kendall

The goals of this research, which was funded by the Texas Higher Education Coordinating Board through the Texas Advanced Research Program, are to develop and apply new techniques of relative and absolute dating of Paleozoic sedimentary rock successions using conodont microfossils. The research is specifically focusing on improving the record of changes in $^{87}Sr/^{86}Sr$ in the world's oceans through the Paleozoic. Existing $^{87}Sr/^{86}Sr$ curves are widely used for dating depositional and diagenetic events in sedimentary rock successions, although the current record is poor for most of the Phanerozoic. Conodonts are uniquely appropriate for improving the $^{87}Sr/^{86}Sr$ record because (1) they are more chemically inert than other materials available for study, being composed of less reactive apatite, and are thus more likely to retain original sea-water chemistries and (2) they are relatively widespread and common in Paleozoic sedimentary successions. Additionally, because conodonts are perhaps the best biostratigraphic tool for the Paleozoic, they facilitate correlation of samples from disparate geographic localities.

Research during the second year of this project focused primarily on determining strontium isotope ratios ($^{87}Sr/^{86}Sr$) in conodonts from Silurian and Devonian sedimentary rock successions. More than 70 Silurian samples were prepared and analyzed. Newly developed techniques have resulted in high-precision analysis of individual conodont elements of as small as 20 mg. Duplicate analyses and measurements of elements from different localities but within the same zone are near or within instrumental precision, which is less than ± 0.000015 2σ. These new data provide a much higher resolution record of secular changes during the Silurian and reveal very subtle changes in $^{87}Sr/^{86}Sr$ that have been unidentified by previous workers. This record is a greatly improved basis for relative dating of sedimentologic events during the Silurian.

Initial results of similar research in Devonian successions suggest that equally significant revisions to the $^{87}Sr/^{86}Sr$ record will result from these studies. Conodont biozonation in the Devonian exceeds biostratigraphic resolution available for the Silurian and affords the opportunity to test the limits of resolution available with this technique. Future research will apply the technique to other parts of the Paleozoic in the southern and central United States.

Gas

Geological Investigations of Low-Permeability Gas Sandstone Reservoirs

Stephen E. Laubach, principal investigator; Mark J. Burn, Sigrid J. Clift, Shirley P. Dutton, H. Scott Hamlin, and Tucker F. Hentz; assisted by Patricia W. Dickerson, Hwanjo Baek, and Eugene M. Kim

Low-permeability formations contain an estimated minimum 900 Tcf of gas in place in the lower 48 states, and increased production from these reservoirs would contribute significantly to the supply of natural gas. The Gas Research Institute (GRI) has supported the Bureau of Economic Geology (BEG) investigations of the geology of low-permeability sandstone reservoirs because geologic properties exert a fundamental influence on reservoir performance and gas production. This BEG effort is part of a broader program designed to increase the understanding and utilization of gas resources in low-permeability formations through integrating geology, formation evaluation, and reservoir engineering.

In 1993, BEG research had three major components: geologic regional and reservoir studies of the Paleocene Wilcox Lobo trend of Webb and Zapata Counties in South Texas and of the Upper Pennsylvanian Canyon Sandstone, Val Verde Basin, Texas, and a generic study of diagenetic controls on fracture occurrence and attributes based on data from GRI research wells in the Upper Cretaceous Frontier Formation of Wyoming, the Lower Cretaceous Travis Peak Formation of East Texas, and the Pennsylvanian Canyon Sandstone. The Wilcox Lobo and Canyon are geologically complex reservoirs that contain substantial amounts of gas that could be produced more efficiently if understanding of reservoir attributes were improved. To develop low-permeability reservoirs fully, the distribution and character of natural fractures must be better understood. Our study is using core and geophysical log data to establish quantitative predictions of fracture occurrence.

In addition to the major study areas, the project carried out preliminary studies of the Pennsylvanian Cherokee sandstone of the western Anadarko Basin, Oklahoma, and Cambro-Ordovician Rose Run sandstone of Ohio, where timely geologic and production-practice assessments were judged to be valuable. Topical reports summarizing these studies were completed in 1993. The Bureau also carried

out various tasks in support of GRI's Technology Transfer Cooperative Well program.

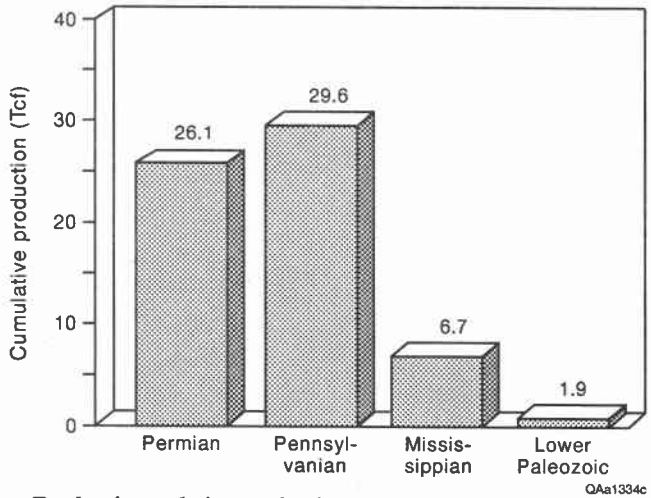
Atlas of Major Gas Reservoirs: Central and Eastern Gulf Coast and Midcontinent

Don G. Bebout, principal investigator; Chester M. Garrett, Jr., William A. White, and Tucker F. Hentz; assisted by John M. Mendenhall and Rick W. Reeves; subcontracts to Arkansas Geological Commission, Louisiana Geological Survey, Mississippi Department of Natural Resources, and Geological Survey of Alabama for the Central and Eastern Gulf Coast portion, and to Arkansas Geological Commission, Kansas Geological Survey, and Oklahoma Geological Survey for the Midcontinent portion

For the past 3 years the Bureau of Economic Geology (BEG) has been under contract with the Gas Research Institute to produce two gas atlases: *Atlas of Major Central and Eastern Gulf Coast Gas Reservoirs* and *Atlas of Major Midcontinent Gas Reservoirs*. BEG, as the prime contractor, issued subcontracts to the geological surveys of Arkansas, Alabama, Kansas, Louisiana, Mississippi, and Oklahoma for basic data gathering and preparing text and illustrations. This project has now been completed and both atlases are available from the Bureau and from most of the participating surveys.

Geological, engineering, and production data on all reservoirs that have produced more than 10 Bcf of gas are included in the atlases' data tables; the data tables are also available separately on computer diskettes. These greater-than-10-Bcf reservoirs were grouped into plays on the basis of similarities in geologic age, lithology, depositional environment, and geographic location. The play concept is an important tool for predicting reservoir characteristics and extending hydrocarbon trends.

In the Central and Eastern Gulf Coast, 1,357 reservoirs that have each produced more than 10 Bcf of gas have been organized into 32 plays ranging in age from Mississippian to Plio-Pleistocene. These 1,357 greater-than-10-Bcf reservoirs have cumulatively produced 60 Tcf of gas, mostly from Louisiana reservoirs (49.6 Tcf). In the Midcontinent, 530 greater-than-10-Bcf reservoirs compose 28 plays, which range in age from Ordovician to Permian. These reservoirs have cumulatively produced 66 Tcf of gas. Of this Midcontinent production, Oklahoma and Kansas have produced 38.7 and 26.5 Tcf, respectively.



Totals of cumulative production by geologic age from natural gas plays of the U.S. Midcontinent region.

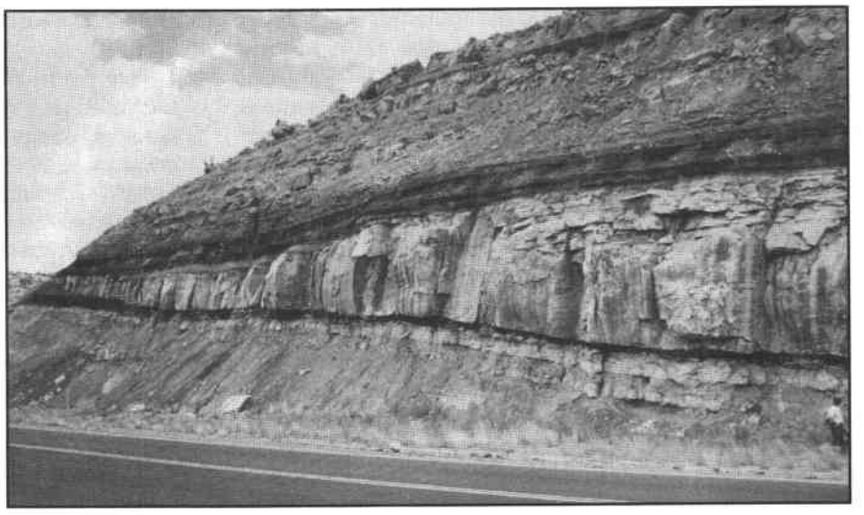
Secondary Natural Gas Recovery: Targeted Technology Applications for Infield Reserve Growth

Robert J. Finley, project director; Raymond A. Levey and Bob A. Hardage, principal investigators; Carol L. Ruthven, Mark J. Burn, and David L. Carr; assisted by Ronald A. Johns, Virginia M. Pendleton, Asad M. Sattar, James L. Simmons, Robert S. Single, Liangqing Xue, and Ran Zhou

The objective of this project, funded by the Gas Research Institute (GRI), the U.S. Department of Energy (DOE), and the State of Texas, is to identify and document the impact of stratigraphic and diagenetic compartmentalization in fluvial-deltaic reservoirs. The Bureau of Economic Geology, the lead technical contractor of this field-oriented gas research project, finalized and documented results on gas compartmentalization in fluvial and deltaic reservoirs in the Gulf Coast Basin in technical articles, topical reports, and short courses. Achievements of this joint venture include (1) confirming that incremental conventional gas resources represent a significant percentage of new gas reserves, (2) assessing the distribution of incremental natural gas resources by depositional system, and (3) defining cost-effective tools and strategies and testing state-of-the-art techniques for achieving incremental recovery of natural gas in mature fields. In the Gulf Coast region, reservoir modeling and engineering analysis is conducted by Research and Engineering Consultants of Englewood, Colorado. ResTech, Inc., of Houston conducts log interpretation and formation evaluation. Envirocorp Services and Technology of Houston has monitored drilling and completion activity and coordinated field-data acquisition in the gas fields in the Gulf Coast region.

Hundreds of gas completions across a spectrum of fluvial reservoirs were evaluated for reservoir compartment size and transmissibility. Stochastic modeling of three dominant compartment size classes indicated that well spacings of 320, 200, and 60 acres provide maximum gas contact efficiency. VSP-calibrated 3-D seismic data indicate that reservoirs as narrow as 200 ft and as thin as 10 ft can be detected at depths approaching 7,000 ft in the interwell space. Facies geometry and resultant flow boundaries between wells identified from project-conducted pressure buildup tests yielded interpreted channel widths averaging 220 ft and as much as 600 ft that matched seismic interpretations.

Application of the utility of this research was confirmed by cooperating with operator-initiated redevelopment in fields that are more than 50 yr old.



Cretaceous coal seams bounding a blocky channel-fill sandstone exposed along the flank of the Uinta Basin, north-central Utah. Variations in the natural-fracture style and sandstone geometry (1) affect the success of coalbed methane wells, (2) compartmentalize and channel gas and water flow, and (3) create traps for gas accumulation. Photograph by Roger Tyler.

Two case studies demonstrated the feasibility of using the SGR approach to convert technically recoverable resources into economically producible reserves without total costs to identify, develop, and produce exceeding the range of $0.60 to $0.80/Mcf.

The region that has the largest potential for natural gas reserve appreciation (after the Gulf Coast Basin) is the Midcontinent region of Oklahoma and Texas, which contains 33 to 41 Tcf of reserve growth resources. A new SGR project is focusing on Pennsylvanian sandstone reservoirs in the Midcontinent region. Research began in Boonsville field in North-Central Texas. Holditch and Associates, Inc., and Scientific Software Intercomp, Inc., are conducting reservoir engineering and petrophysical research in this new Midcontinent study region. Project workers have an active working relationship with three gas operators (OXY U.S.A., Inc., in Midland; Enserch Exploration, Inc., in Dallas, and Threshold Development Corp. in Fort Worth). The largest 3-D seismic survey ever acquired in the Fort Worth Basin, covering approximately 30 mi^2, is being used to study the Atoka interval of Boonsville field. Plans in 1994 include analyzing deltaic gas reservoirs in Oklahoma, in cooperation with the Oklahoma Geological Survey.

Geologic and Hydrologic Controls on Coalbed Methane Production

William R. Kaiser, principal investigator; Douglas S. Hamilton, Andrew R. Scott, and Roger Tyler; assisted by Ronald G. McMurry, Naijiang Zhou; in cooperation with the West Virginia Geological Survey and Colorado Geological Survey

The objective of this project, funded by the Gas Research Institute (GRI), is to determine geologic and hydrologic controls on the production of coalbed methane. The Bureau of Economic Geology is characterizing coalbed methane in western United States coal basins; the Colorado Geological Survey is subcontracted for collecting data and logistical support. The West Virginia Geological Survey (WVGS) is subcontracted to study the Northern Appalachian Coal Basin in northern West Virginia and southwestern Pennsylvania.

Characterization of coalbed methane resources in the Greater Green River Basin continued with completion of a detailed geologic and hydrologic study of the Sand Wash Basin, northwest Colorado and southwest Wyoming, and an ongoing survey of the rest of the greater basin. The results of the Sand Wash study are available as GRI Topical Report GRI-92/0420; key findings are summarized there.

The Sand Wash Basin, a structurally complex basin, has a predominant northwest-trending structural grain of diverse origins. Northwest and northeast maximum horizontal stresses are expressed dynamically in a combined thrust and strike-slip (wrench) fault segmentation of the basin and in local areas of crosscutting and mutually abutting face-cleat strikes and fracture swarms. Total coal gas resources in the basin are 101 Tcf, reflecting large coal resources of 377 billion short tons. More than 90 percent of the gas resources and almost 75 percent of the coal resources are in the Upper Cretaceous Williams Fork Formation; the remainder are in the Paleocene Fort Union Formation. Orientation and distribution of Williams Fork and Fort Union coal are governed by shoreline and fluvial sandstones, respectively. Net-coal thicknesses are greatest in the east part of the basin and correspond to sandstone thicks.

To date, low gas content (<200 ft^3/ton) and high water production (hundreds of barrels per day), reflecting low coal rank, proximity to recharge, and high coalbed permeability, have limited coalbed methane activity in the basin. Coalbed wells drilled along the east and southeast margins of the basin have yielded little gas and large volumes of water. The basin's cumulative gas–water ratio is approximately 15 ft^3/bbl. The most prospective coals lie basinward in the Williams Fork Formation, where deeper drilling should mean higher gas contents because of higher reservoir pressure and

coal rank. Gas contents in some Williams Fork coals associated with the Cedar Mountains fault system northwest of Craig, Colorado, exceed 400 ft^3/ton. Moreover, because permeability in the hydropressured section is high overall, the permeability floor for coalbed methane exploration in the basin may be lower than normally expected in western coal basins. Areas of overlapping cleat domains may have higher permeability and could be favorable targets for open-hole cavity completions, which have proved successful in the northern San Juan Basin.

High productivity requires that geologic and hydrologic controls on production (permeability, ground-water flow direction, coal distribution and rank, gas content, depositional fabric, and structural grain) be synergistically combined. That synergism is evident in a comparison of the prolific coal-gas-producing San Juan Basin and marginally producing Sand Wash Basin. From a comparison between the two basins, a basin-scale coalbed methane producibility model is evolving; its essential elements are ground-water flow through thick coals of high rank and high gas content orthogonally toward no-flow boundaries (permeability barriers) and conventional trapping of gas along them. The model remains to be tested and refined in other coal basins.

In studies of coalbed methane in the Northern Appalachian Coal Basin, the WVGS has completed its study of the Middle Pennsylvanian Allegheny Formation, the major coal-bearing units below the basal Monongahela Pittsburgh coal. A draft report is under review and should be available sometime next year. In the report, the Allegheny was operationally defined to include strata between the Brush Creek marine zone, a regional marker, and the massive Group sandstones. Allegheny coals are thickest and most continuous in the lower part of the operational formation. Net-coal thickness is typically 10 to 20 ft but exceeds 20 ft in several areas and occurs as two to eight seams that are commonly 1 to 3 ft thick, having maximum thicknesses of 5 to 8 ft. The orientation and distribution of the Allegheny coal are governed by the fluvial depositional fabric. Net-coal thicks (>20 ft), elongate west, northwest, and southwest and less than 6 mi wide, probably do not extend entirely across the basin. They correspond or lie immediately adjacent to channel sandstone belts. Large areas of thick net coal lie in Doddridge and Westmoreland Counties.

Electric Power Research Institute (EPRI) Gas Book

Robert J. Finley, principal investigator

On behalf of the Electric Power Research Institute (EPRI), the Bureau of Economic Geology (BEG) conducted a brief evaluation of factors influencing natural gas reserve growth as a contribution to natural gas supply. EPRI's interest in this issue stems from its members' interest in natural gas as a fuel for generating electric power, particularly to meet near-term needs and to apply to peak loads in this decade. Results of the study were presented at an EPRI workshop in Houston and will be published by EPRI.

Interest in natural gas reserve growth potential has increased as a result of studies by BEG, the U.S. Department of Energy, the Energy Information Administration, and in late 1992, the National Petroleum Council (NPC). The NPC estimated that 236 Tcf of natural gas reserve growth resources exist in the lower 48 states. The Bureau has shown that reserves of natural gas in known fields increase as the fields continue to be developed, even in mature fields discovered more than 50 years ago, if the fields contain geologically complex reservoirs. Tools to define and develop this resource now include advanced geological modeling, improved cased-hole well logs, and 3-D surface seismic. The reserve resource benefits in its development in wells that can be recompleted in new zones and that have existing gas production infrastructure. As a result, the reserve growth resource is being developed at current moderate wellhead prices and will be a key contributor in supplying electric generation.

Update of Atlas of Major Texas Oil Reservoirs Data Base and Atlas of Major Texas Gas Reservoirs Data Base

Mark H. Holtz, project manager; Robert J. Finley and Noel Tyler, principal investigators; Chester M. Garrett, Jr., and Thomas A. Tremblay

Updating both the *Atlas of Major Texas Oil Reservoirs: Data Base* (Holtz and others, 1991) and the *Atlas of Major Texas Gas Reservoirs: Data Base* (Garrett and others, 1991) involved updating cumulative production data current through December 31, 1991, on reservoirs already in the data bases and adding new significant-sized reservoirs (cumulative production greater than 1 MMboe) to the data bases. Adding new reservoirs to the data bases resulted in our modifying existing geologic plays or determining new plays. We also modified play boundaries to accommodate the additional reservoirs. New plays were described in a contract report prepared for the U.S. Geological Survey (USGS), the project's funding agency. The new plays and data will be applied to USGS's ongoing assessment of U.S. hydrocarbon resources.

Updating the *Atlas of Major Texas Oil Reservoirs: Data Base* (Holtz and others, 1991) resulted in a more than sevenfold increase in the number of reservoirs, changing the data set from 450 reservoirs to more than 3,270. The addition of these reservoirs resulted in the identification of 10 new oil plays and the modification of all play boundaries.

Updating the *Atlas of Major Texas Gas Reservoirs: Data Base* (Garrett and others, 1991) resulted in a more than threefold increase in the number of reservoirs, changing the data set from 1,578 reservoirs to more than 4,821. Because of the inclusiveness of the original play scheme, no new plays were added; however, most play boundaries were modified.

Coal

Computerized Calculation of Lignite Resources in Texas

William R. Kaiser, principal investigator; Mary L. W. Jackson; assisted by Scott C. Goode

This long-term project, funded by the U.S. Geological Survey (USGS), provides estimates of remaining near-surface lignite resources. The computerized data base and graphics software of the National Coal Resources Data System (NCRDS) are used to calculate resources according to criteria in USGS Circular 891 (Coal Resource Classification System of the U.S. Geological Survey) and criteria consistent with current mining practice in Texas.

Resource calculations on a five-quadrangle test area in South Texas were finished by year's end. Three different methods for converting data files into lignite-thickness contours have been evaluated, and a preferred method has been selected. It has been included in a script that will be used as a standard for calculating Wilcox and Jackson lignite resources throughout South Texas. As data files on East Texas become accessible from NCRDS, the same method will be used for revising Jackson–Yegua resource calculations in East Texas.

Experimental and Applied Tectonics Investigations

Applied Geodynamics Laboratory: Physical Tectonic Modeling

Martin P. A. Jackson, principal investigator; Bruno C. Vendeville and Hemin Koyi; assisted by Hongxing Ge

The Applied Geodynamics Laboratory (AGL) makes physical scale models for generating new concepts, testing hypotheses, or occasionally duplicating specific geologic structures relevant to the location, origin, mechanics, and evolution of structural traps for oil and gas. Research at AGL is funded by a consortium of industrial associates comprising the following oil companies: Agip S.p.A., Amoco Production Company, ARCO Oil and Gas Company, BP Exploration, Inc., Conoco, Inc., Du Pont Corporation, Exxon Production Research Company, Marathon Oil Company, Mobil Research and Development Corporation, Petróleo Brasileiro S. A., Phillips Petroleum Company, Société Nationale Elf Aquitaine Production, Texaco, Inc., and Total Minatome Corporation.

Most experiments were carried out in a normal gravity field. The deformation rig allows simulation of almost any structural style, including extension, shortening, wrenching, doming, and drape folding, or any combination of these styles. The rig is driven by two stepper motors controlled by two electronic indexers and a personal computer. A biaxial rig also allows experiments that have simultaneous shortening or extension in two directions. For modeling in an accelerated gravity field, a high-speed, high-capacity centrifuge was used. The machine is equipped with a viewing hatch, stroboscopic lighting, and digital speed and temperature controls. Other pieces of equipment built for the experiments include a highly accurate coaxial viscometer for measuring flow properties of modeling materials, a motorized sheet roller for manufacturing sheets of putty, and a slicing jig. Accessory equipment includes two motorized deformation tables and four cameras. Modeling materials include silicone polymers, silicone putties, Plasticine, quartz sands, glass sand, glass bubbles and beads 25 to 60 microns in diameter, clays, paraffin waxes, petrolatum, rosin, dyes, and computer-generated, printable grids of strain markers.

Experimental research during the year continued to focus on a wide range of gravity-driven tectonics involving diapirism, extension, contraction, and combinations of these structural styles. Experiments covered the following main topics:

(1) Growth and lateral intrusion–extrusion mechanisms of salt tongues induced by progradation. (This research examines how salt tongues break out from the source layer and cut upward across the stratigraphy),

(2) Role of the prograding wedge in driving parallel and radial flow of salt by differential loading and gravity spreading,

(3) Control of basement block faulting on coeval diapirism and overburden faulting and folding, some targeted variables being (a) the relative thickness of source layer and overburden compared with the throw of the basement fault, (b) the relative rates of extension and sedimentation, and (c) interacting effects of nonparallel grabens below and above salt layers,

(4) Contraction superposed on diapirs formed in an extensional field, which ranged from mild inversion to severe overthrusting and pinching of diapiric stems, and

(5) Systematic study of salt withdrawal from salt structures of different shape to simulate structures formed by salt dissolution.

Applied Geodynamics Laboratory: Mathematical Tectonic Modeling

Martin P. A. Jackson, principal investigator; Daniel D. Schultz-Ela and Giovanni Guglielmo, Jr.

The AGL makes mathematical scale models for generating new concepts or testing hypotheses relevant to the formation of structural traps for oil and gas. Research at AGL is funded by a consortium of industrial associates comprising the following oil companies: Agip S.p.A., Amoco Production Company, ARCO Oil and Gas Company, BP Exploration, Inc., Conoco, Inc., Du Pont Corporation, Exxon Production Research Company,

Marathon Oil Company, Mobil Research and Development Corporation, Petróleo Brasileiro S. A., Phillips Petroleum Company, Société Nationale Elf Aquitaine Production, Texaco Inc., and Total Minatome Corporation.

Mathematical modeling uses several Macintoshes and digitizers, a Silicon Graphics Indigo workstation, and a variety of software, some of it developed at AGL. Most of the mathematical modeling involves numerical modeling, which comprises boundary-element modeling and finite-element modeling.

The finite-element modeling uses GEOSIM-2D, a program that can simulate combinations of viscous and plastic flow, large finite strains, faulting, sedimentation, and erosion. The program is jointly owned by EUROSIM Sarl and Total Compagnie Française des Pétroles. Two topics were systematically investigated: (a) factors causing structural asymmetry of diapirs piercing brittle overburden during regional extension and (b) structures above and adjacent to active diapirs forcefully intruding a brittle layer.

Various software solutions were investigated, and developing software for visualizing salt and other structures in three dimensions was begun.

Applied Geodynamics Laboratory: Structure of Upheaval Dome, Utah

Martin P. A. Jackson, principal investigator; Daniel D. Schultz-Ela; assisted by Hongxing Ge

Field mapping of Upheaval Dome was funded by Exxon Production Research Company. Other funds were supplied by the AGL Industrial Associates, comprising the following companies: Agip S.p.A., Amoco Production Company, ARCO Oil and Gas Company, BP Exploration, Inc., Conoco, Inc., Du Pont Corporation, Exxon Production Research Company, Marathon Oil Company, Mobil Research and Development Corporation, Petróleo Brasileiro S. A., Phillips Petroleum Company, Société Nationale Elf Aquitaine Production, Texaco, Inc., and Total Minatome Corporation.

Upheaval Dome is a breached, subcircular Mesozoic dome underlain by Permian Paradox evaporites. Three-dimensional exposures suggest that Upheaval Dome may represent the pinched-off stem of a salt dome. The overhanging diapiric bulb or salt extrusion postulated to have overlain the stem would have been removed by erosion during elevation of the Colorado Plateau. Pinched-off, pancake-shaped diapirs are common in the subsurface Gulf of Mexico. Although diapiric necking in fluid overburdens has been modeled extensively, necking of viscous salt in a brittle overburden, which is much more relevant to salt tectonics, has never been investigated. Upheaval Dome presents a potential opportunity at surface to examine in three dimensions the brittle response to diapiric pinch-off.

The structural and stratigraphic mapping around Upheaval Dome focused on (1) gathering evidence for a protracted growth history, which would support Upheaval Dome's origin as a salt dome, and (2) determining this structure's mode of emplacement by linked fault systems in the overburden. The dome is rimmed by a monoclinal kink where the negligible regional dip abruptly steepens into a prominent rim syncline. The inner limb of the rim syncline dips outward at ≤60°. Overall, dips increase inward from the synclinal trace, elevating strata above regional datum. In both limbs of the rim syncline, circumferential extensional faults thin strata. These axisymmetric, ramp-flat extensional faults dip mostly inward but also outward. Nearer the center, the Kayenta Formation is thickened into centripetal thrust duplexes and circumferential and radial folds. These fold and fault systems are consistent with necking of a diapiric stem. The core of the diapir contains a complex pattern of imbricate thrust faults arranged roughly radially about a hub invaded by contorted clastic dikes.

Land, Water, and Environmental Resources Investigations

Environmental, Geologic, and Hydrogeologic Studies

Geologic and Hydrogeologic Studies of the Eagle Flat Region, Hudspeth County, Texas

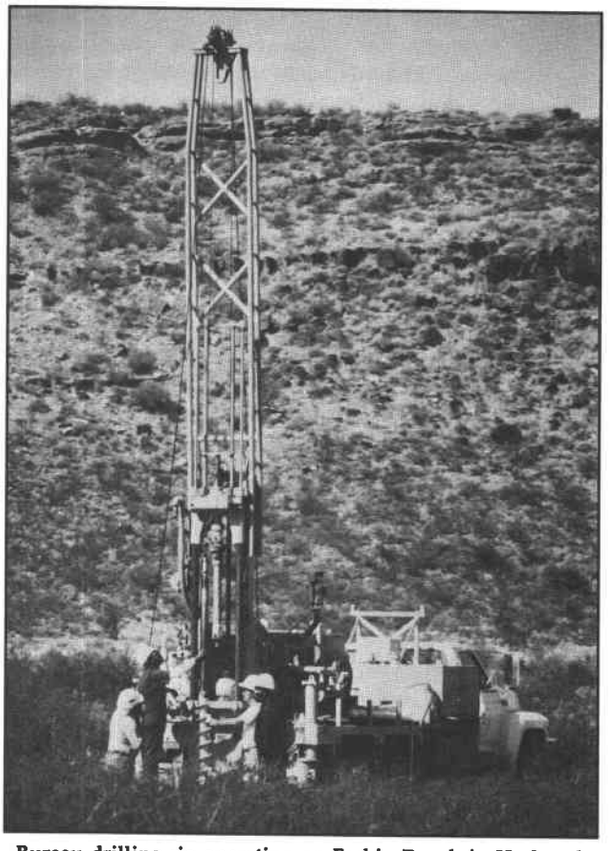
Jay A. Raney, principal investigator; Edward W. Collins, Bruce K. Darling, Richard S. Goldsmith, Barry J. Hibbs, Mary L. W. Jackson, Richard P. Langford, William F. Mullican III, Jeffrey G. Paine, Bridget R. Scanlon, Allan R. Standen, G. Stephen Stubbs, Steven W. Tweedy, E. G. Wermund, and Jiannan Xiang; assisted by Yao-Chang Chang, Liang Chen, Scott C. Goode, Jun Liao, Ian C. Jones, Sreevathsa Ramachandra, and Richard Whitt

The Bureau of Economic Geology (BEG) has been the State's primary contractor for geologic and hydrogeologic characterization of the proposed site for the Texas low-level radioactive waste repository. In 1993 we completed the data acquisition and analysis phase of the investigation, and we continue to be responsible for some monitoring activities and other support. These studies are funded by the Texas Low-Level Radioactive Waste Disposal Authority.

The proposed site of the Texas repository is located on Faskin Ranch about 6 mi east of Sierra Blanca in Hudspeth County, Trans-Pecos Texas. BEG's geologic and hydrologic investigations encompass both the regional framework and site-specific characteristics of the site and active processes that may impact the design and performance of the repository. The results of our studies

are being used by engineers designing the facility and by Texas regulators who will evaluate the technical adequacy of the site. The studies are designed to be comprehensive in scope. In addition to meeting the objectives of the State, we have also advanced our understanding of the geology and geohydrology of a large region in the Trans-Pecos.

Our investigations of the surficial geology, basin-fill sediments, and neotectonics have greatly increased our knowledge of late Cenozoic development of the region. On the basis of field studies of surficial deposits, radiocarbon dates, and analyses of calcic soils, the mid-Pleistocene to modern evolution of the landscape has been investigated. The current surface is quite stable, and rates of erosion and aggradation are generally low. Working jointly with our peers at The University of Texas at El Paso, we applied seismic techniques and paleomagnetic analysis to investigate the development of previously little understood basin-fill sediments of the Eagle Flat Basin, which contains the proposed site. At the proposed site, basin-fill sediments are approximately 150 to 700 ft thick. These are mostly fine-grained clastic sediments that contain local sand and gravel channels. The deepest part of the basin that we have sampled includes basin-fill deposits that are approximately 12 Ma old. BEG's new drill rig was a major asset to both our geologic and vadose-zone studies because it allowed us to obtain excellent samples of the shallow subsurface (depths of less than 100 ft) at low cost.



Bureau drilling rig operating on Faskin Ranch in Hudspeth County, West Texas. A site in the Eagle Flat Basin on the north end of Faskin Ranch has been proposed as the location of the State of Texas repository for low-level radioactive wastes. Bureau researchers use the rig to collect samples and install monitoring equipment for studying basin-fill sediments and the hydrology of the unsaturated zone, two elements of a comprehensive geologic and hydrologic characterization of the ranch and surrounding region. Photograph by Jay A. Raney.

Studies of the vadose zone expanded our understanding of vadose-zone processes in arid to semiarid settings, which can be applied to many other regions of the western United States and other areas having similar climates and geologic settings. Soil physics was used to monitor water movement in the vadose zone for the duration of the monitoring program, and chemical tracers, such as chloride and chlorine-36, were used to evaluate long-term variations in water movement related to paleoclimatic change. The physical and hydrochemical investigations of the saturated zone have much improved the definition of regional flow systems and the evolution of the hydrochemistry of the aquifers. Numerical models based on field data, pump tests, and our knowledge of the geohydrologic framework also help to refine our quantitative description of the ground-water system. Information developed as part of this investigation will also be used by local residents seeking to develop additional sources of ground water.

Consolidated Research Program: U.S. Gulf Coast Geopressured-Geothermal Program

Steven J. Seni and Robert J. Finley, principal investigators; assisted by Suk-Joo Choh

The Gulf Coast Geopressured-Geothermal Program is part of a long-term cooperative agreement between the U.S. Department of Energy, The University of Texas Center for Petroleum and Geosystems Engineering, and the Bureau of Economic Geology. The ultimate goal of the program is to demonstrate the economic viability of geopressured-geothermal water as a reliable, domestic source of alternative energy. In a five-county area of South Texas (Zapata, Webb, Duval, Jim Hogg, and Starr Counties), known geopressured-geothermal fairways in the deep Wilcox Group lie below the shallow Jackson–Yegua Barrier/Strandplain Sandstone play. Geothermal fluids produced from the Wilcox Group could be injected into shallow heavy-oil reservoirs to supply both the heat energy and fluid necessary for enhanced oil recovery by steam or hot-water flooding. Although some South Texas Wilcox geothermal reservoirs are characterized by high temperatures (as much as 500 °F), their ability to produce large volumes of hot water is severely constrained by low permeability. In 1993, research concentrated on reservoir characterization of Prado field, as a representative of a large field in the Jackson–Yegua Barrier/Strandplain Sandstone play.

Because sandstone reservoirs in the Jackson–Yegua Barrier/Strandplain Sandstone play are characterized by

low recovery efficiencies, and they contain a large hydrocarbon resource target potentially amenable to advanced recovery techniques such as geothermal water flooding. Prado field, Jim Hogg County, South Texas, has produced more than 23 MMbbl of oil and more than 32 Bcf of gas from combination structural-stratigraphic traps in the Eocene lower Jackson Group. Hydrocarbon entrapment at Prado field results from differential compaction, anticlinal nosing, and updip pinch-out of barrier-bar sandstone. Relative base-level lowering resulted in forced regression, which established lower Jackson shoreline sandstones in a relatively distal location in central Jim Hogg County. Reservoir sand bodies at Prado field comprise complex assemblages of barrier-bar, tidal-inlet fill, back-barrier bar, and shoreface environments. Subsequent progradation built the barrier-bar system seaward 1 to 2 mi. Within the barrier-bar system, targets favorable for hydrocarbon reexploration have concentrated in tidal-inlet facies because they have the most depositional heterogeneity.

Geologic and Hydrologic Characterization of Pantex Plant

Thomas C. Gustavson, principal investigator; Alan E. Fryar, Richard S. Goldsmith, Susan D. Hovorka, William F. Mullican III, Jeffrey G. Paine, Bridget R. Scanlon, Allan R. Standen, G. Stephen Stubbs, Steven W. Tweedy, and Jiannan Xiang; assisted by Martina U. Blüm, Stephen R. Allen, George T. Bush, Yao-Chang Chang, Min-Yuan Cheng, Alex Y. Colunga, Jordan W. Forman, Jr., Randall K. Hill, Anselmo S. Jacobo, Leslie B. Kelley, Steven M. Rooks, and Claude Strickland

In September 1990, funded by a DOE grant to the Governor's Office, the 5-year project to characterize the hydrology and geology of the U.S. Department of Energy's (DOE) Pantex Plant near Amarillo, Texas, began. The Pantex Plant is currently the national site for assembling, maintaining, and disassembling nuclear weapons. Previous DOE environmental surveys have revealed local contamination of soil, sediment, and perched ground water beneath the Pantex Plant.

Because DOE is required by applicable Federal and State regulations to remediate and monitor areas of contamination at the Pantex facility, the Bureau of Economic Geology (BEG) and its subcontractors are conducting investigations on and off the Pantex Plant to enable the State to assess DOE's cleanup efforts independently. Under BEG's leadership and using a multidisciplinary approach, scientists and engineers are describing the stratigraphy, structure, hydrology, geochemistry, and playa-lake biological systems to determine the fate and transport of contaminants at the Pantex Plant. BEG is responsible for stratigraphic, structural, groundwater, and some geochemical studies. The Department of Geological Sciences at The University of Texas at Austin and the Center for Water Resources at Texas Tech University are responsible for studying the geochemistry of playa-lake sediments, surface-water hydrology, and the fate and transport of contaminants in playa-lake sediments. Data from these studies, in conjunction with other data from characterization studies being carried out by the U.S. Army Corps of Engineers and Battelle/Pantex, will provide an integrated view of the geologic framework and hydrologic processes involved in ground-water recharge primarily from playas, development of a perched aquifer, and flow in the Ogallala aquifer.

Multidisciplinary studies at the Pantex Plant have been designed to determine transport mechanisms, transport rates, and the fate of potential contaminants that include gasoline, solvents, high explosives, and their derivatives. Research objectives are to determine:

- the rates and processes by which runoff is collected in playa basins and recharged through the unsaturated zone to an extensive perched aquifer and eventually to the Ogallala aquifer,
- the chemical evolution of contaminants as they pass through playa biota and underlying sediments,
- the hydrology and water chemistry of the Ogallala and perched aquifers, and
- the depositional systems of the Ogallala and Blackwater Draw Formations and playa sediments.

During the first year, field studies of the upper Tertiary Ogallala and Quaternary Blackwater Draw Formations and playa-lake basins began. Several water wells at the Pantex Plant were instrumented, sampled, and monitored, and approximately 40 km of high-resolution-reflection seismic data were collected. Ogallala ground-water and subsurface stratigraphic data bases on the Pantex Plant and surrounding region were assembled. Preliminary hydrologic modeling of the unsaturated zone began.

The second year of investigations at the Pantex Plant was highlighted by our completing two stratigraphic test wells at the plant and by our acquiring approximately 20 km of shallow high-resolution seismic data south of the plant. The stratigraphic test wells were completed as ground-water monitoring wells of the perched aquifer and the Ogallala aquifer. Twenty additional shallow wells designed to provide core from the Blackwater Draw Formation and hydrologic data from the unsaturated zone were also completed.

Preliminary interpretation of hydrologic and stratigraphic data indicates that aquifers on the High Plains are primarily recharged from runoff collected in playa basins. In addition, a large perched aquifer lies beneath much of the Pantex Plant at a depth of about 250 ft. Waters in the perched aquifer contain tritium, which was derived from atmospheric testing of atomic weapons, suggesting that these waters were recharged from the surface within the last 40 yr. The apex of the broadly cone shaped perched aquifer is located beneath playa 1, which is the discharge point of surface drainage ditches at the Pantex Plant.

During year 3, as part of regional hydrologic and geologic investigations, 41 boreholes were drilled in 6 different playa basins. The total depth of these boreholes ranges from 10 to 120 ft; approximately 2,819 ft of con-

tinuous core was collected for analysis. Examination of the core shows that 40 to 60 ft of lake sediments is beneath the floors of playa lakes. Recharge to the perched and Ogallala aquifers may be influenced by areas of increased permeability, such as mineralized fractures or eolian sand layers within the lacustrine clays, lacustrine delta facies, or upland silty loam facies interfingering with lacustrine clays. At Sevenmile Basin, a large playa basin less than 1 mi south of the Pantex Plant, three seismic refraction spreads were completed and 4.5 km of seismic reflection data were collected. Interpretation of these data indicates that subsidence beneath Sevenmile Basin is probably related to dissolution of Permian evaporites and collapse of overlying strata. The hydrologic characteristics and lateral extent of the perched aquifer(s) are much better understood because of 2 new observation wells that have been drilled, completed, and tested by BEG at the Pantex Plant; 22 new static water-level measurements at the Pantex Plant and 4 new static water-level measurements near the Pantex Plant that have been made from perched aquifer(s) monitors and domestic supply wells; 2 new pumping tests; and the completion of numerous ground-water flow simulations that focused on the perched aquifer(s). Eight boreholes were drilled to depths of 43 to 105 ft to evaluate differences in subsurface moisture fluxes between playa and interplaya settings, including two at the Pantex Plant. Soil samples from these boreholes were analyzed for water content and chloride concentration and indicate that the playas are focal points of recharge. Neutron probe access tubes were installed in the TDCJ playa and adjacent interplaya settings to monitor temporal variations in water content. A multistep constant head borehole test was developed and applied to measure the conductivity of layered soils at Pantex. An extensive data base from new monitor wells producing from the perched and Ogallala aquifers at the Pantex Plant, as well as from privately owned water wells in the region of the Pantex Plant, has been assembled. This new information is being used to construct and refine ground-water flow models that have been constructed for the two hydrologic systems. Preliminary analyses of soil gases suggest that the source of elevated carbon dioxide in sediments below playas is microbial degradation of organic carbon. Analyses of ecological processes in playa wetlands, hydrologic modeling of the rainfall-runoff process, and estimation of historic wastewater flows and quality continue.

Assessment of Storage in the Edwards Aquifer

Alan R. Dutton, principal investigator; Susan D. Hovorka, Stephen C. Ruppel, and Joseph S. Yeh; assisted by Sudarsan S. Parthasarathy, Martina U. Blüm, and Ronald A. Johns

The purpose of this 8-month study, funded by the Edwards Underground Water District, is to estimate the total storage of the Edwards aquifer in the San Antonio region. We found that resource allocation in this geologically complex, prolific, and economically important unit can be improved, on the basis of an estimate of the amount and distribution of water in the aquifer. Geophysical logs were used to construct a three-dimensional model of the stratigraphy and porosity distribution in the Edwards aquifer. An empirical approach, developing a facies-specific correlation between the log response and the measured rock properties, yields more accurate porosity calculations than do standard conversions.

Porosity distribution in the Edwards aquifer is complex because several diagenetic events have been overprinted on a highly cyclic, laterally variable porosity distribution. In shallow-water carbonate environments on the San Marcos Platform (Bexar, Hays, Comal, and Medina Counties), vertical heterogeneity was produced by upward-shoaling cycles in the Kainer and Person Formations. Many grainstones preserve high original porosity in subtidal cycles, whereas sequences of tidal-flat-capped cycles tend to have diagenetically enhanced porosity in dolomitized subtidal facies. Later diagenesis further complicated the porosity distribution by preferential dissolution and replacement of dolomite by calcite, evaporite dissolution, karstic dissolution of calcite, and solution enhancement of fracture porosity. Porosity in the grainstone-dominated Devils River Formation, marginal to the San Marcos Platform, includes intergranular porosity and evaporite- and karstic-solution-enhanced porosity. The Maverick Basin facies include the low-porosity, subtidal West Nueces Formation, subtidal evaporites having solution and solution-collapse porosity in the McKnight Formation, and fine-grained grainstones and packstones of the Salmon Peak Formation having high depositional and solution-enhanced porosity.

Porosity in the Kainer and Person Formations ranges from 42 percent in leached dolomite to 4 percent in subtidal facies. Porosity of the 170-m-thick Edwards Formation in Bexar County averages 22 percent. Higher average porosity is mapped in Hays and Comal Counties and in southern Bexar and Medina Counties on both sides of the fresh–saline water interface. In the west part of the aquifer, the low-porosity West Nueces and McKnight Formations are overlain by the Salmon Peak Formation. Porosity in the Salmon Peak Formation increases toward the north.

A hydrologic estimate of the storativity in the confined part of the aquifer was made using barometric efficiency and the porosity data generated from logs.

Environmental Atlas of the Rio Grande–Rio Bravo Border Area

Jay A. Raney, principal investigator

This project, funded by the U.S. Environmental Protection Agency, is the first step toward compiling an environmental atlas of the Rio Grande–Rio Bravo Border Area between the United States and Mexico. The Border Area, as defined in the Border Environmental Plan, is the 100-km-wide strip on each side of the international border between the United States and Mexico. An assessment of the information available on this critical environmental

area, on both sides of the border, is in progress, the objective being to summarize the available data and identify gaps in the data base. Eventually a Geographic Information System (GIS) digital map will depict geologic, hydrologic, and natural resource information on the Border Area, which can be amplified by other layers of information as they are compiled. Protocols for the GIS procedures are being described in a Quality Assurance document.

Paleohydrology of the Nonglaciated Great Plains: Climatic and Geomorphologic Implications

Alan R. Dutton, principal investigator

Although ground water is a valuable resource beneath the U.S. High Plains, little is known about its age or hydrologic history. This research, funded by the U.S. Geological Survey (USGS) as part of its Water Resources Research Section 105 Grant Program, is designed to determine whether age and source of unconfined and confined ground waters are the same beneath the central, northern, and southern High Plains, and to consider the implications of variations in isotopic composition of ground water for late Cenozoic paleoclimatology of the continental interior. This is one of only a few studies to infer paleoclimatic conditions from ground-water composition.

Results show that confined ground waters, isotopically distinct from unconfined ground waters in the High Plains aquifer, were recharged approximately 15 to 35 ka ago during the Wisconsinan (late Pleistocene) glaciation. The north-to-south range in isotopic composition of confined ground waters is smaller than that of either unconfined ground water or Modern meteoric waters. In the central and southern High Plains, isotopically light ground water appears to reflect a cool and possibly wet climate during the Wisconsinan. Enriched isotopic composition in confined aquifers beneath the northern High Plains, however, does not likely represent the presence of warm tropical air. Paleoclimatic weather simulations at the time of glacial maximum (~18 ka) show bifurcation of the North American jetstream and an anticyclonic circulation that might account for cold, isotopically heavy, North Atlantic moisture being drawn across the continental interior. Changed amounts of winter and summer precipitation and changed amounts of moisture derived from the Pacific and Atlantic Oceans and the Gulf of Mexico could have affected isotopic composition of precipitation.

Climatic conditions must have persisted long enough for the "new" ground water of distinct isotopic composition to percolate through the confining layers and flush "old" water from the confined aquifers. If age of ground water in confined aquifers is assumed to resemble residence time, and if several pore volumes must pass through the heterogeneous strata to displace older ground water, then climatic conditions must have remained relatively constant for at least 45 to 105 ka for the confined aquifers to have their present composition. Since the end of the Pleistocene, enough time has elapsed for recharge to replace older ground water in the unconfined aquifer, where ground water has a shorter residence time.

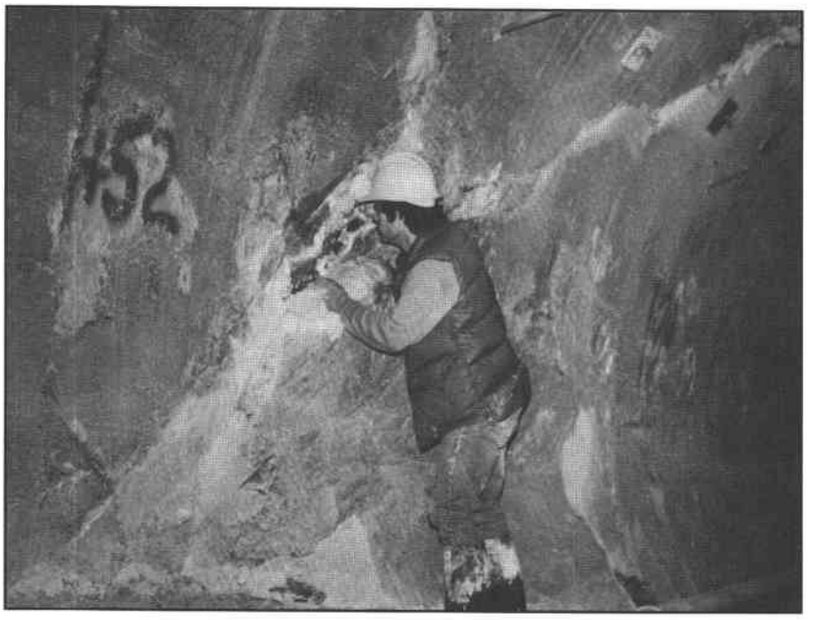
Hydrogeologic Studies in Support of the Superconducting Super Collider (SSC)

Alan R. Dutton, principal investigator; Alan J. Cherepon, Susan D. Hovorka, Robert E. Mace, H. Seay Nance, and Rainer Senger; assisted by Martina U. Blüm, Erika M. Boghici, Ganesh P. S. Rao, and Corbin D. Smith

The purpose of this study, supported by the Texas National Research Laboratory Commission (TNRLC), is to develop a comprehensive account of the occurrence and movement of ground water near the SSC in Ellis County, Texas. The SSC was scheduled to be constructed in the Austin Chalk and the Ozan and Eagle Ford Formations. Work during 1993 included completion of topical reports, continued stratigraphic and hydrologic analysis of regional aquifers, and mapping of fractures and faults exposed in surface excavations and tunnels at the SSC site. A draft ground-water protection management plan was prepared for the SSC Laboratory.

Fractures are probably the primary conduit of ground-water flow in these formations because unfractured bedrock has low hydraulic conductivity. Distribution and fabric of detrital versus authigenic clays, rather than total clay content, influence the mechanical properties and log response of chalk and marl. These fracture characteristics might account for differences in overbreaks around the collider tunnel. The three-dimensional expression of faults and joints in the SSC tunnel and surface excavations are being mapped in detail. Such mapping will provide a record of possible fracture-controlled paths of ground-water flow near the SSC tunnel, as well as a unique geological data set.

Water levels in both weathered and unweathered bedrock generally mimic topography, reflecting a dynamic balance between rate of recharge from precipitation and rates of discharge by evapotranspiration, flow to springs and seeps, and pumping of wells. Chemical composition and salinity of ground waters are controlled by mineralogic reactions and incomplete flushing of ancient seawater. Flushing of marine salts is most complete in the near-surface weathered zone and in unweathered bedrock where fractures are most abundant and interconnected. ^{14}C and ^{3}H data suggest that ground water in fractured bedrock was recharged within the last 40 to 50 yr. Only a small amount (<1 percent) of the ground water moving through the surficial weathered bedrock moves downward into unweathered, low-permeability bedrock. Vertical circulation of ground water in fractured zones is locally deep. Ground water in bedrock having less well interconnected fractures was possibly recharged within the past 15,000 to 20,000 yr and average ground-water age in unweathered, unfractured bedrock is 1,000,000 yr.



Bureau scientist examines a mineralized fault in the lower Austin Chalk exposed in the wall of the Superconducting Super Collider (SSC) tunnel in Ellis County, Texas. Mapping of numerous fractures in the tunnel and in surface excavations is part of a larger, comprehensive study of ground-water movement at the SSC site. Photograph by Kenley C. Schroeder.

The estimated well density on and around the SSC footprint is 9.1 wells/mi^2. Many of the 2,700 unused or abandoned shallow wells in the study area, in poor repair, have been used as trash receptacles, creating a potential for contaminating the shallow aquifer.

Ground-water flow in regional aquifers in the Woodbine, Paluxy, and Twin Mountains Formations is being modeled to predict future water-level decline. Since the mid-20th century, ground-water withdrawal from deep regional aquifers has caused major declines in water levels. The predictive flow model is being based on hydrogeologic characteristics of the aquifer, particularly aquifer thickness, transmissivity, and storativity as derived from hydrologic test data and geologic maps describing the stratigraphy and depositional facies of the aquifer units. Model parameters are calibrated on the basis of historic changes in water levels and potentiometric surfaces. The completed and tested model will be made available to agencies and water-supply companies responsible for assessing future water-resource availability.

Using Nitrogen Isotopes to Trace Nonpoint Source Contamination

R. Stephen Fisher, principal investigator

Determining the source, mobility, and flow paths of contaminant nitrate in ground water is essential to developing prevention and remediation procedures and to formulating management policy in agriculture. In areas of multiple land use and nonpoint sources of contaminants, identifying contaminant sources and flow paths can be exceedingly difficult. Erath County, Texas, is one such area where land is used in dairy farming and raising crops and trees. Preliminary analyses of shallow ground waters show that some ground waters contain nitrate concentrations that are more than three times the EPA maximum contaminant level.

This research will identify contaminant sources by comparing the stable nitrogen isotope composition of potential nitrate sources such as fertilizer, animal waste, and natural soil nitrogen with that of nitrate in shallow ground waters. A second objective of the research is to conduct preliminary evaluation of two potential flow paths for nitrate entry into the ground-water system. Direct recharge from surface water will be evaluated by comparing the distribution of nitrate concentrations and stable isotope compositions in surface water with that in shallow ground water. We will also sample the unsaturated zone and measure the concentration and stable nitrogen isotope composition of nitrate-nitrogen to evaluate the potential for irrigation-induced recharge.

During 1993, we established field and laboratory procedures for collecting ground- and surface-water samples, analyzing nitrate- and ammonium-nitrogen in water samples and measuring the $\delta^{15}N$ isotope composition of nitrate- and ammonium-nitrogen in water samples. During the fall of 1993, we collected surface- and ground-water samples from selected drainages and wells in Erath County, chemically and isotopically quantified nitrate and ammonium-nitrogen in each sample, and provided a final report to the Texas Applied Environmental Research Institute at Tarleton State University.

Environmental Surveys of Texas National Guard Training Sites

E. G. Wermund, principal investigator;
Arten J. Avakian and H. Seay Nance;
assisted by Joel M. Adrian and Mary E. Sansing

The Bureau of Economic Geology summarized the geomorphology, climate, geology, soils, and surface and ground waters of Camp Bowie, Camp Swift, and King Ranch training sites in Bastrop, Brown, and Kleberg Counties, respectively, in final reports accompanied by discs of digitized maps. Similar studies began describing the physical environments at Camp Mabry and Fort Wolters in Travis and Parker Counties. Remaining training sites will be studied in 1994.

Using Electromagnetic Geophysical Surveys to Locate Nonpoint Sources of Natural Salt Water Pollution of the Canadian River, Texas and New Mexico

Thomas C. Gustavson, principal investigator;
Arten J. Avakian, Susan D. Hovorka, Jeffrey G. Paine, and Bernd C. Richter

The Canadian River carries approximately 53,000 metric tons of dissolved halite (NaCl) annually and a nearly equal amount of gypsum ($CaSO_4$). These high-total-dissolved-solid (TDS) waters discharge into Lake Meredith, which is the primary source of drinking water for most municipalities on the Texas High Plains from Amarillo on the north to Lubbock and Brownfield on the south. The salinity of Lake Meredith has increased dramatically over the last 10 yr, from approximately 200 ppm to more than 400 ppm, and must be diluted with Ogallala water to reduce its salinity enough to meet EPA drinking-water standards (250 ppm). In all of these communities, production of large volumes of water from the Ogallala aquifer with which to blend Lake Meredith waters is expensive. Furthermore, Ogallala ground-water levels are declining because rates of domestic, agricultural, and industrial water use exceed recharge rates.

The objective of part I of this study, which was completed in late 1992, was to assist the Canadian River Municipal Water Authority in determining the sources of saline water discharged into the Canadian River. The Bureau completed a conductivity survey and collected and analyzed water samples to identify segments of the Canadian River that were receiving saline waters. The Bureau also prepared detailed cross sections identifying areas of halite and gypsum dissolution along the northwest margin of the Palo Duro Basin near the Ute Reservoir. Areas of primary concern lie along the Canadian River in New Mexico 12 to 20 km downstream of the Ute Reservoir, near the Texas–New Mexico border 30 to 60 km downstream of the Ute Reservoir, and near Lahey Creek north of Amarillo, Texas.

Part II of this study will use conductivity surveys (EM surveys) to locate saline ground-water plumes in alluvium or bedrock in the floor of the Canadian River valley. EM systems, having a transmitter coil and a receiver coil, allow electrical current to flow in the transmitter coil, creating a primary magnetic field. A secondary magnetic field is created by current induced to flow in the subsurface by the primary magnetic field. In shallow surveys, induced currents flow mostly in fluids that fill pores in subsurface strata. Conductivity of the pore fluid increases almost linearly as salinity increases in the fluid; changes in the primary magnetic field caused by subsurface current flow are detected by the receiver coil.

Locating saline ground-water plumes in alluvium and bedrock along a 150-km segment of the river upstream of Lake Meredith is the first step in any remediation process designed to reduce salinity levels in the Canadian River and Lake Meredith. In the first phase of investigation dramatic increases in river salinity were identified in eastern New Mexico. Chloride concentrations increased from ~0 mg/L at Logan, New Mexico, to ~8,000 mg/L at the Texas–New Mexico border. Conductivity increased from <1,000 to >10,000 micromhos/cm along the first 6 mi below Ute Reservoir, New Mexico. Phase 2 analyses of ground conductivity were focused along river segments in which increases in salinity and conductivity were identified in phase 1. Measurements were made along seven segments of the Canadian River and its tributaries between Ute Dam and the Texas–New Mexico border. Electromagnetic surveys located 4 broad high-conductivity zones and 18 individual conductivity peaks that apparently represent sites of saline ground-water inflow into the Canadian River system. Joint analyses suggest that ground water in the Canadian River valley flows preferentially along east-west joint sets, which appear relatively open at the surface and are commonly at least partly mineralized by calcite.

Now that sources of high-TDS waters have been identified, engineered remediation is being planned, which will likely require installing production wells, pumping contaminated ground water to draw down the local ground-water table and reduce or eliminate discharge of contaminants to the Canadian River, and reinjecting these waters into deep subsurface strata. Part I of this research was funded by the Canadian River Municipal Water Authority; part II was funded by the Texas Water Development Board.

Hydrogeochemical Controls on Naturally Occurring Radioactive Materials in Oil- and Gas-Field Operations

R. Stephen Fisher, principal investigator;
assisted by Eric W. James and Nina L. Baghai

Naturally occurring radioactive materials (NORM), chiefly radium, commonly occur at low levels in water that is produced with oil and natural gas. Scale and sludge that have formed in oil- and gas-field equipment commonly contain NORM, chiefly radium, ranging from background-level concentrations to levels found in uranium-mill tailings. High concentrations must be

identified because they pose a health threat to those who come in contact with contaminated equipment. Furthermore, although safe disposal of NORM scale and sludge may require special methods and facilities, measuring and monitoring radiation levels to ensure safe conditions at each well and facility is costly and time-consuming, particularly for small operators. This research is designed to identify geologic, geographic, geochemical, and production controls on NORM and to provide operators a screening methodology for identifying whether reservoir characteristics and production techniques at their fields and wells favor the formation of NORM precipitates.

We are evaluating two hypotheses regarding NORM in produced water and oil- and gas-production equipment scale. The first is that NORM is produced locally by high uranium and thorium concentrations in the reservoir rocks. If this is generally true, NORM scale will be largely controlled by geographic area or geologic formation. The second hypothesis is that NORM is released from geologic media during normal diagenetic processes. If this is generally true, the potential for NORM scale precipitation can be predicted largely from the mineralogy, burial depth, and temperature of the reservoir. Determining which of these hypotheses is correct will enable us to improve our ability to predict where NORM scale is most likely to accumulate in unhealthy amounts.

Our approach is to investigate geochemical, geological, and production parameters that control the occurrence of NORM in produced waters and in oil- and gas-field equipment. We are addressing two fundamental questions: what controls the concentration of radium in formation water, and what controls the precipitation of NORM-containing scale? We interpret relations between reservoir setting (geographic area, geologic formation, pressure, temperature, and brine chemistry) and NORM content of brine and scale using published data in addition to chemical and mineralogical analyses of brines and scales collected at field sites.

We have completed our survey of relevant literature and have compiled all available data on NORM scale in Texas. We have established methods of modeling brine and scale compositions geochemically and have accumulated data on the geochemical behavior of uranium, thorium, radium, barium, and sulfate in formation water. We have also identified two large sets of oil- and gas-field brines that have been previously collected and analyzed for other projects and that are available for radium determinations. Our focus now is to establish analytical capabilities, determine what additional fields should be sampled, collect brine and scale samples, and proceed with analyses and geochemical modeling of the results.

Bureau researchers preparing to take a shallow core in a freshwater marsh along the lower Trinity River, Texas Gulf Coast, as part of an investigation of sedimentation rates and wetland loss. The study will determine the levels of river inflow and sediment load needed to sustain wetland elevations. Photograph by William A. White.

Coastal Studies

Determining Recent Sedimentation Rates of the Trinity River, Texas

Robert A. Morton and William A. White, principal investigators; assisted by Lisa E. Remington

This project has grown out of a previous investigation of sedimentation and marsh loss in fluvial-deltaic areas of the Texas coast, funded by the Texas Water Development Board through its Water Research and Planning Fund. Approximately 30 percent of the marsh system in the lower reaches of the alluvial valley and delta of the Trinity River has been lost over the past 3 decades. Most of the loss results from conversion of interior vegetated wetlands to water and flats, indicating that marsh sedimentation rates have not kept pace with rates of subsidence and sea-level rise. A principal objective of this study was to assist the Texas Water Development Board in defining river inflow and sediment load parameters that are needed to sustain wetland elevations and periodically replenish wetland habitats with additional river-borne sediment.

The general methodology was to determine rates of river sedimentation that are necessary for maintaining existing wetland habitats in a setting where past rates of relative sea-level rise have locally exceeded 10 mm/yr. A total of 12 shallow cores were taken in brackish and fresh marshes of the Trinity River fluvial-deltaic system for physical and chemical analysis. Sedimentation rates were determined by isotopic analyses of excess ^{210}Pb activity, which were performed by Dr. Charles Holmes of the U.S. Geological Survey in Denver. Total organic carbon and textural analysis of the cores were conducted by the Bureau's Mineral Studies Laboratory and Core Research Center. Other analyses included water content, mineral matter, and bulk density.

Preliminary results of the distribution of excess ^{210}Pb activity with depth in most cores suggest at least two rates of sedimentation for different time periods. The

Texas Water Development Board will use the sedimentation data to determine the relationship between river flooding and sediment deposition in order to define river inflow sediment load requirements to maintain wetlands. Benchmark releveling surveys indicate that subsidence rates have declined since the late 1970's as a result of reductions in ground water pumpage in the east part of the Houston subsidence region. This suggests that sedimentation rates necessary to maintain marsh habitats above a rising relative sea level may be lower than during the past 2 decades, when subsidence rates were substantially higher.

Geological Investigation of Wind-Tidal Flat Area, Kenedy County, Texas

Robert A. Morton, principal investigator;
L. Edwin Garner; assisted by Lisa E. Remington

The wind-tidal flats of Kenedy County, Texas, have long been the focus of geological investigations because they lie between Padre Island to the east and a vast complex of sand dunes (eolian plain) forming the uplands to the west. The flats and eolian plain are also aligned with the predominantly southeasterly wind, and they coincide with the arc of Padre Island where the average positions of alongshore currents in the western Gulf of Mexico meet. The flats are periodically flooded by marine water that is derived from the deeper parts of Laguna Madre. The water is driven onto the flats by strong and persistent winds; hence the term wind-tidal flats.

In 1993, the Bureau of Economic Geology conducted a geological investigation of the wind-tidal flats for the Texas Office of the Attorney General. The primary objectives of the study were to determine whether any significant surficial changes had occurred in and around the flats of Kenedy County since the late 1800's and to investigate the geologic history of the area over the past few hundred years. The latter task includes explaining the dominant physical processes responsible for flat construction, examining the sediments beneath the flats, and interpreting the geological significance of the sedimentary sequences. The study was supported by fieldwork and laboratory analyses. The fieldwork involved collecting sediment cores at selected sites on the flats, whereas the laboratory analyses involved examining maps and aerial photographs, as well as performing chemical and physical analyses of the cores. The laboratory analyses established the composition, textures, and ages of the sediments beneath the flats.

Monitoring the Beach and Vegetation Line on Galveston Island

Robert A. Morton, principal investigator; Jeffrey G. Paine, Roberto Gutierrez, and James C. Gibeaut

In August 1983, Hurricane Alicia crossed the Texas coast, causing substantial beach erosion and extensive damage to houses near the shoreline. Scouring action by storm waves and currents undermined many homes, destroyed bulkheads, and caused natural vegetation to retreat landward. The purpose of this study is to provide current information concerning magnitudes and rates of recovery of the beach and vegetation line after a major storm. Also under study is how human activities influence recovery processes. This information should prove useful to (1) owners of coastal property that is subject to storm damage and (2) public officials responsible for reviewing and permitting activities in the Coastal Zone. The study involves examining recent aerial photographs and measuring the beach profile at selected sites in undeveloped areas of West Beach, Galveston Island, and Follets Island.

In 1993, an experimental beach survey that had been conducted in 1991 was repeated at Galveston Island State Park using Global Positioning System (GPS) technology. The purpose of the repeat survey was to test the accuracy and repeatability of GPS measurements and to develop new methods for surveying long stretches of open coast. Results of the experiment showed that (1) GPS surveys can be repeated with centimeter-level accuracy, (2) beaches can be monitored more rapidly and efficiently when using GPS methods than when using conventional surveys, and (3) minor changes in beach morphology can be detected using GPS technology. The two-dimensional beach surveys conducted in 1991 and 1993 were compared and a computer routine was used to map and calculate the volume differences between the two surveys.

Characterization of Sand Bodies within Seismic Sequences—Texas Continental Margin

Robert A. Morton, principal investigator;
assisted by Cynthia A. Jennings

This project, which was initiated in 1989, is funded by the U.S. Department of the Interior, Minerals Management Service, as part of its Continental Margins Program. The primary objective of this research is to improve the prediction of lithologies and the identification of potential reservoir facies within depositional sequences on the basis of seismic patterns and reflection terminations. Upper Quaternary depositional sequences preserved beneath the continental shelf were selected for detailed study because of the existing shallow subsurface control and the constraints on sea-level fluctuations that occurred during the past 100,000 yr. This work is being accomplished by integrating and analyzing two data sets—high-resolution seismic surveys and foundation borings.

In 1993, the physical properties (thickness, percent sand, lithologies), depositional environments, and paleogeography were mapped for four seismic sequences (pre-Wisconsin, Early Wisconsin, Late Wisconsin, Holocene, and Modern) that had been identified previously. A final contract report was prepared that summarized the geologic history of the study area and emphasized the influence of sea-level fluctuations and salt mobilization on sequence development and deposition of sand bodies within each sequence. At year end, plans were being made to extend the study onto the adjacent continental slope

where the deep-water facies will be examined using foundation borings, cores, and high-resolution seismic profiles.

Analysis and Prediction of Coastal Erosion and Wetland Loss in Southeastern Texas

Robert A. Morton, principal investigator; James C. Gibeaut and William A. White; assisted by Joan M. Drinkwin and Lisa E. Remington

Coastal erosion and wetland loss in Texas are occurring at rapid rates in some areas that are undergoing rapid economic development. Erosion and submergence threatens transportation networks, a large industrial complex, ports, and high-density development, as well as a nationally based economy. Understanding and solving these problems require an extensive quantitative data base and predictive models that can forecast changes. To address these needs, the Bureau of Economic Geology and the U.S. Geological Survey have initiated a 5-yr cooperative study of the southeastern Texas coast extending from Sabine Pass to Sargent Beach.

The purpose of the study is to develop information and expertise needed to ensure that economic development of the coastal region is compatible with a dynamic system. Specific objectives of the study include: (1) providing technical data on coastal erosion and land loss to government, industry, and coastal planners, (2) predicting rates of coastal erosion and land loss, (3) evaluating the impacts of recent hurricanes and predicting impacts of future hurricanes, (4) evaluating the impact of relative sea-level rise on coastal lands and communities, and (5) identifying and evaluating offshore and nearshore sand resources for possible beach restoration.

The 5-yr study will have six major work elements: (1) coastal erosion analysis, (2) regional geologic framework investigations, (3) coastal processes analysis, (4) predictions of future coastal responses, (5) sand resources investigations, and (6) technology transfer activities. During 1993 we compiled and assembled existing data and information, updated shoreline change maps, mapped shoreline types, investigated wetlands changes, developed computer programs for statistically analyzing shoreline movement, tested the Digital Shoreline Mapping System (DSMS) developed by the USGS, and collected a series of cores using the Bureau of Economic Geology's drilling rig. This multidisciplinary approach is designed to provide a better understanding of the geological evolution of the southeastern coast and to offer a basis for predicting the changes that might occur in the future.

Coastal Mapping and Shoreline Monitoring Projects

Robert A. Morton, principal investigator

In 1993, the Bureau conducted a study for the Beach and Dune Task Force of the Town of South Padre Island. Technical assistance involved identifying the optimum zone for reestablishing and protecting fore-island dunes, updating recent maps of shoreline movement, and developing a program to monitor the beaches and dunes of South Padre Island. A report titled *Beach and Dune Conditions at South Padre Island, Texas—Assessment and Recommendations* was prepared that summarizes the status of beaches and dunes and makes recommendations regarding preservation of the beach and dune system.

Bureau coastal scientists also conducted work for the Texas General Land Office as part of its Coastal Zone Management Program. Rates of historical Gulf shoreline erosion along developed beaches in Texas were summarized, classified, and compiled on a map showing shoreline stability. A report titled *Shoreline Movement along Developed Beaches of the Texas Gulf Coast: A User's Guide to Analyzing and Predicting Shoreline Changes* was prepared that explains how shoreline change is analyzed and illustrates the history of shoreline movement at regularly spaced transects along the Gulf shoreline.

Mineral Resources Investigations

Texas Mining and Mineral Resources Research Institute

Jay A. Raney, director; Christopher D. Henry, Eric W. James, and Edward W. Collins; assisted by Linda L. Davis and David G. Edgerton

The Texas Mining and Mineral Resources Research Institute (TMMRRI) is supported by the U.S. Bureau of Mines and dedicated to research and education in mineral resources. The Bureau of Economic Geology administers TMMRRI; academic affiliates include The University of Texas at Austin, Texas A&M University, and Prairie View A&M College. TMMRRI awards competitive graduate fellowships, postdoctoral research positions, research assistantships, and undergraduate scholarships. During the 1993–1994 academic year, three fellowships were awarded to support graduate research in ore deposition, mining engineering, and lignite.

Research under TMMRRI using field mapping, geochemical analysis, detailed petrography, isotopic dating, and computer modeling of hydrothermal processes focuses on the relationship between ore formation and contemporaneous igneous and tectonic activity. Two broad topics have been of continuing interest: (1) rare metal resources in Trans-Pecos Texas and (2) the sources of metals for ore deposits. Research also continues into the effects of late Cenozoic tectonism in Trans-Pecos Texas.

TMMRRI research has used Pb isotopic tracers to identify both the source of metals in ore deposits and the origin of related igneous rocks. Metals in ore deposits in Texas represent a mix of igneous, basement, and sedimentary sources. This year field studies have been initiated in the Franklin Mountains and areas adjacent to the Hueco Bolson.

Mapping Investigations

Geologic Studies of the Big Bend Ranch State Natural Area

Christopher D. Henry; William R. Muehlberger (Department of Geological Sciences); Larry McCormick (Long Island University, New York); Mick Kunk and John Sutter (U.S. Geological Survey, Reston, Virginia); assisted by Linda L. Davis

Geologic mapping of Big Bend Ranch State Natural Area, one of the newest and largest units of the Texas Parks System, was completed this year. It was jointly funded by the Texas Parks and Wildlife Department and the U.S. Geological Survey's (USGS) Cooperative Geologic Mapping Program (COGEOMAP). This mapping was part of a long-term Bureau of Economic Geology (BEG) project that focuses on mapping volcanic centers of the mid-Tertiary volcanic fields of Trans-Pecos Texas.

The Big Bend Ranch State Natural Area owes its rugged beauty and much of the diversity of its biological and cultural resources to the complexity of the geology. The intriguing story of the geological evolution of this area will be described in Bureau publications. One report focuses on the geology of the Solitario, a remarkable structural dome formed in Paleozoic strata during mid-Tertiary volcanic activity, and the other will be a somewhat more general description of the geology of the area including the Bofecillos Mountains, a volcanic highland built up by a series of volcanoes. These reports will be used by the Parks and Wildlife Department in its ongoing studies of the area and will be sold to visitors who want further information about the natural history of the park.

Although preparation of the final report for this part of COGEOMAP is now nearly complete, additional mapping in Trans-Pecos Texas will occur under the new STATEMAP program. This mapping, also funded jointly by USGS and BEG, is beginning in the Rio Grande valley near El Paso in the Hueco Bolson. The results of this work, which is being carried out by Jay A. Raney, Edward W. Collins, and Richard P. Langford, will be reported next year.

Geologic Atlas of Texas

Virgil E. Barnes, principal investigator

Because geologic atlas sheets have been published for the entire state, new work focuses on revising and reprinting older maps as they go out of print. The Lubbock, Perryton, and Palestine sheets were revised and reprinted this year. The Llano, Emory Peak, Corpus Christi, Waco, Seguin, and Laredo sheets were reprinted without changes.

Mapping (1:100,000) of New Braunfels, Texas, Quadrangle

Jay A. Raney, principal investigator; Edward W. Collins and William P. Elder (U.S. Geological Survey, Menlo Park)

The objective of this multiyear project is to map the geology of the 1:100,000-scale New Braunfels, Texas, Quadrangle. The map area covers a rapidly developing part of Central Texas that includes Wimberley, Canyon Lake, Guadalupe River State Park, New Braunfels, northern San Antonio, Lake Medina, Boerne, and Comfort. This area lies on the southwest limb of the San Marcos Arch and includes a complex part of the Balcones Fault Zone, where its strike changes markedly. The Balcones Fault Zone is the southeast limit of the Cretaceous outcrops that are part of the recharge zone of the Edwards limestone aquifer, and it marks the northwest edge of the Texas Coastal Plain. This project, part of the U.S. Geological Survey's (USGS) Cooperative Geologic Mapping Program (COGEOMAP), will continue in 1994 under the new USGS STATEMAP program. It is funded jointly by the USGS and the Bureau of Economic Geology, and in-kind services provided by USGS include paleontologic studies. The geology is being mapped on 1:24,000-scale 7.5-minute quadrangles; a composite map will be published using the new USGS 1:100,000-scale topographic map of the area as a base.

The third year of this project focused on completing mapping of the southeast quarter of the 1:100,000-scale New Braunfels, Texas, Quadrangle. Draft geologic maps of the 7.5-minute quadrangles composing the New Braunfels–eastern San Antonio area were completed this year. These maps are Bat Cave, Bulverde, Marion, McQueeney, New Braunfels East, New Braunfels West, and Schertz Quadrangles. Units that crop out in this area are Cretaceous limestone, marl, and shale. Upper Cretaceous deposits that occur southeast of the Balcones Escarpment are mostly covered, as are Eocene claystone, mudstone, siltstone, and sandstone. Quaternary sand and gravel cover much of the older deposits near the Guadalupe River and Cibolo Creek. Normal faults of the Balcones Fault Zone mostly strike N40°–70°E. Mapping of the west half of the 1:100,000-scale New Braunfels, Texas, Quadrangle began in late 1993 and will continue during 1994.

Entrance to the north wall of McKittrick Canyon, site of the Permian Reef Geology Trail, Guadalupe Mountains National Park, West Texas. A full-color guidebook published by the Bureau details the stratigraphy and carbonate facies encountered along the trail. Photograph by Don G. Bebout.

Other Geologic Investigations

Trail Guide—McKittrick Canyon Permian Reef Geology Trail, Guadalupe Mountains National Park

Don G. Bebout and Charles Kerans, principal investigators

The Permian Reef Geology Trail in the mouth of McKittrick Canyon, Guadalupe Mountains National Park, traverses 2,000 vertical ft (5,000 to 7,000 ft topographic elevation) of Permian (upper Guadalupian) facies through one of the world's finest examples of a rimmed carbonate platform. The present-day topography approximates that formed by the Capitan reef along the edge of the Delaware Basin. The trail, constructed by the U.S. National Park Service in the early 1980's, provides easy access to well-exposed depositional facies and diagenetic features of this shelf margin. The goal of this project was to develop a trail guide documenting the stratigraphy and carbonate facies encountered along the Permian Reef Geology Trail. The trail guide, published by the Bureau of Economic Geology in September 1993, is available for purchase at the Visitor Centers of the Guadalupe Mountains and Carlsbad Caverns National Parks as well as at the Bureau of Economic Geology, The University of Texas at Austin. Authors of the trail guide include R. G. Loucks and Alton Brown, ARCO; P. M. Harris, Chevron; B. L. Kirkland, The University of Texas at Austin; Denise Mruk, Marathon; E. L. Stoudt and S. A. Longacre, Texaco; and Charles Kerans and Don G. Bebout, Bureau of Economic Geology.

Financial support of the trail guide was provided by ARCO Resources Technology, Carlsbad Caverns–Guadalupe Mountains Association, Chevron Petroleum Technology Company, David E. Eby, Exxon Company, U.S.A., Mobil Research & Development Corporation, Texaco E&P Technology Division, and Union Pacific Resources.

Contract and Grant Support

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

Contract-management personnel prepare proposals and budgets, negotiate contracts, and monitor expenditures. During the contract period, technical and financial reports are distributed at monthly, quarterly, and annual intervals. In 1993, the following 68 contracts, each of which had reporting requirements, were active at the Bureau:

Federal

"Analysis and Prediction of Coastal Erosion and Wetland Loss in Southeastern Texas": supported by the U.S. Geological Survey, U.S. Department of the Interior.

"Computerized Calculation of Lignite Resources, Jackson and Wilcox Trends, South Texas (Revision) and Jackson–Yegua Trend, East Texas (Revision)": supported by the U.S. Geological Survey, U.S. Department of the Interior.

"Conducting Technology Transfer Seminars": supported by the U.S. Department of Energy through the National Institute for Petroleum and Energy Research.

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"El Paso STATEMAP Project": supported by the U.S. Geological Survey, U.S. Department of the Interior.

"Environmental Atlas of the Rio Grande/Rio Bravo Border Area": supported by the U.S. Environmental Protection Agency.

"Geologic and Hydrologic Site Characterization of the Pantex Plant": supported by the U.S. Department of Energy through the Office of the Governor.

"Geologic Studies of West Texas Bedded Salt Deposits": supported by the U.S. Department of Energy.

"Geology of the Bofecillos Mountains and Big Bend State Natural Area, Trans-Pecos Texas": supported by the U.S. Geological Survey, U.S. Department of the Interior.

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

"Hydrogeochemical and Production Controls on NORM in Oil- and Gas-Field Operations": supported by the U.S. Department of Energy.

"Mapping (1:100,000) of New Braunfels, Texas, Quadrangle": supported by the U.S. Geological Survey, U.S. Department of the Interior.

"Mining and Mineral Resources Research Institute Fellowships": supported by the Bureau of Mines, U.S. Department of the Interior.

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"New Braunfels STATEMAP Project": supported by the U.S. Geological Survey, U.S. Department of the Interior.

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

"Paleohydrology of the Nonglaciated Great Plains: Climatic and Geomorphologic Implications": supported by the U.S. Geological Survey, U.S. Department of the Interior.

"Produce a Generic Slide Show": supported by the U.S. Army Corps of Engineers.

"Revitalizing a Mature Oil Play: Strategies for Finding and Producing Unrecovered Oil in Frio Fluvial-Deltaic Reservoirs of South Texas": supported by the U.S. Department of Energy.

"Secondary Natural Gas Recovery: Targeted Technology Applications for Infield Reserve Growth": supported by the U.S. Department of Energy and the Gas Research Institute (two contracts).

"Studies Related to Continental Margins (years 3 through 10)": supported by the Minerals Management Service, U.S. Department of the Interior (eight contracts).

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

State and Local

"Advanced Exploration and Development Research for Revitalizing Hydrocarbon Recovery in the Permian Basin, West Texas": supported by the Texas Higher Education Coordinating Board.

"Analysis of the Physical Attributes of Camp Mabry and Fort Wolters National Guard Training Sites": supported by the Texas Adjutant General's Department.

"Assessment of Storage in the Edwards Aquifer": supported by the Edwards Underground Water District.

"Beach and Dune Work Plan, South Padre Island": supported by the town of South Padre Island.

"Center for State Lands Energy Resource Optimization": supported by the Office of the Governor.

"Comprehensive Hydrogeologic Investigations of Regional Ground-Water Flow and Ground-Water Resources, Ellis County Area, North Texas": supported by the Texas National Research Laboratory Commission (two contracts).

"Conodont Chemostratigraphy: Improvements in the Geologic Time Scale through Strontium and Uranium–Thorium–Lead Isotopic Dating": supported by the Texas Higher Education Coordinating Board.

"Determining Recent Sedimentation Rates of the Trinity River, Texas": supported by the Texas Water Development Board.

"Determining Recent Sedimentation Rates of the Lavaca River, Texas": supported by the Texas Water Development Board.

"Development and Application of the Nitrogen Isotope Tracer in Evaluating Hydrogeologic Controls on Abatement of Non-Point Source Pollution from Livestock Confined Feeding Areas and Other Agricultural Operations": supported by Tarleton State University (two contracts).

"Evolution of the Earth's Early Atmosphere: Evidence from Earliest Proterozoic Platform Carbonates": supported by the Texas Higher Education Coordinating Board.

"Geological Investigation of Wind–Tidal Flat Area, Kenedy County, Texas": supported by the Office of the Attorney General.

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

"Geology of the Big Bend Ranch State Natural Area": supported by the Texas Parks and Wildlife Department.

"Hydrologic Study of Fayette and Colorado Counties": supported by the Lower Colorado River Authority.

"Investigation of Saline Water Contamination in the Canadian River and Lake Meredith": supported by the Texas Water Development Board.

"Maps of Shoreline Changes along Developed Segments of the Texas Gulf Shoreline": supported by the Texas General Land Office.

"Maximization of Petroleum Recovery Efficiency": supported by the Texas Higher Education Coordinating Board.

"Planning Environmental Management of the Texas National Guard Training Areas": supported by the Texas Adjutant General's Department.

"Quality Assurance Assistance for a Low-Level Radioactive Waste Disposal Facility, Hudspeth County, Texas": supported by the Texas Low-Level Radioactive Waste Disposal Authority (two contracts).

"Technology Transfer to Independent Oil and Gas Operators": supported by the Texas Higher Education Coordinating Board.

"Texas Highway Department—Archeological Projects": supported by the Texas Department of Highways and Public Transportation (now the Texas Department of Transportation).

Private

"Applied Geodynamics Laboratory": supported by Total Minatome Corporation, Phillips Petroleum Company, Conoco, Inc., BP International, Ltd., Marathon Oil Company, Agip S.p.A., Mobil Exploration & Production, Petróleo Brasileiro S. A. Petrobras, E. I. Du Pont de Nemours and Company, Texaco Services, Inc., Elf Aquitaine (Production), Chevron Petroleum Technology Company, and ARCO Exploration and Production Technology.

"Atlas of Major Gas Reservoirs: Central and Eastern Gulf Coast and Midcontinent": supported by the Gas Research Institute.

"Characterization and Quantification of Geologic and Petrophysical Heterogeneity in Fluvial-Deltaic Reservoirs": supported by the Gas Research Institute.

"Characterization of Eocene Reservoirs: LL-652 Area, Lake Maracaibo, Venezuela": supported by Lagoven S. A.

"Characterization of Heterogeneity Style and Permeability Structure in Fluvial Reservoirs, Açu Formation, Brazil": supported by Petróleo Brasileiro S. A.

"Characterization of Heterogeneity Style and Permeability Structure in a Sequence Stratigraphic Framework in Fluvio-Deltaic Reservoirs": supported by Japan National Oil Corporation, Amoco Production Company, STATOIL, Intevep, BP Exploration Operating Company Limited, Chevron Oil Field Research Company, Conoco, Inc., Société Nationale Elf Aquitaine (Production), Exxon Production Research Company, Mobil Research and Development Corporation, Occidental International Exploration and Production, Inc., and OXY U.S.A., Inc., Oryx Energy Company, and Union Oil Company of California.

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"EPRI Gas Book": supported by Energy Ventures Analysis, Inc.

"Geologic Analysis of Primary and Secondary Tight Gas Sands Objectives": supported by the Gas Research Institute.

"Geologic and Hydrologic Controls on Coalbed Methane Production: Western Basin": supported by the Gas Research Institute.

"Integrated Characterization and Strategic Development of Tirrawarra Field, South Australia": supported by Santos, Ltd.

"Secondary Natural Gas Recovery—Infield Reserve Growth Joint Venture: Applications in Mid-Continent Sandstones": supported by the Gas Research Institute and the U.S. Department of Energy.

Publications

In its role as a public geological research unit, the Bureau disseminates the results of research projects and programs primarily through its own publication series. During its 83-year history, the Bureau has published nearly 2,250 reports, bulletins, circulars, special publications, and maps covering major aspects of the geology and natural resources of Texas. Publications are sold at nominal prices to recover printing or duplication costs. To date, more than 1.7 million publications have been distributed worldwide, mostly through direct sales. During 1993, about 20,000 volumes were distributed. The Bureau issued the following publications in 1993.

Report of Investigations

RI 211.
Major Low-Permeability-Sandstone Gas Reservoirs in the Continental United States

by S. P. Dutton, S. J. Clift, D. S. Hamilton, H. S. Hamlin, T. F. Hentz, W. E. Howard, M. S. Akhter, and S. E. Laubach. 221 p., 171 figs., 33 tables, $10.00

Approximately 25 percent of the natural gas resource base of the continental United States occurs in low-permeability ("tight gas") sandstones. In this report, the authors characterize this important unconventional resource by summarizing geologic, engineering, and production information on 24 low-permeability, natural-gas-bearing sandstone formations in 13 sedimentary basins: Anadarko, Appalachian, Denver, East Texas and North Louisiana, Fort Worth, Green River, Maverick, Permian, Piceance, San Juan, Texas Gulf Coast, Val Verde, and Wind River. Estimated ultimate recovery from existing wells in 21 of the formations, for which compiled production data are available, is 47.1 Tcf. The 24 formations were selected because either they contain abundant natural gas reserves and resources or the geologic and engineering data available for characterizing them could apply to other, similar gas-bearing formations. Each formation summary is divided into (1) introductory information on thickness and depth of the formation, data availability, and previous studies, (2) depositional systems and reservoir facies, (3) composition and diagenesis of reservoir facies, (4) natural fractures, (5) engineering characteristics, and (6) production history. Illustrations include location maps, stratigraphic columns, cross sections, structure maps, core descriptions, stress profiles, typical logs (including porosity logs), porosity-permeability cross-plots, and capillary-pressure curves. Funding was provided by the Gas Research Institute under contract no. 5082-211-0708, but the report is a publication jointly issued by the Bureau of Economic Geology and the Gas Research Institute.

Geological Circulars

GC 93-1.
Historical Shoreline Changes in Copano, Aransas, and Redfish Bays, Texas Gulf Coast

by J. G. Paine and R. A. Morton. 66 p., 30 figs., 5 tables, 3 appendices, $6.00

Analyses were completed of shoreline movement in both major (Copano, Aransas, and Redfish) and minor (Port, Mission, and St. Charles) bays in the Copano Bay system. To do so, the authors compared aerial photographs, measured shoreline movement, and calculated rates of change during particular times. Observed long-term changes in shoreline position provide estimates of the relative stability of shorelines and allow comparisons of shoreline changes before and after human modifications became significant. Shoreline changes between the early 1930's and the late 1950's, the late 1950's and 1982, and the early 1930's and 1982 are summarized in tables and on maps. The authors report that, despite the widespread use of shoreline-protection measures, shorelines in the Copano Bay system retreated at an average rate of 0.8 ft/yr between the 1930's and 1982. Rates of retreat were higher during the more recent period (2.5 ft/yr between the late 1950's and 1982) than during the earlier period. The authors attribute the increased erosion to low water levels in the 1950's, a higher incidence of major hurricanes since the late 1950's, increased coastal development, and higher recent rates of relative sea-level rise.

GC 93-2.
Gas Reservoir Quality Variations and Implications for Resource Development, Frio Formation, South Texas: Examples from Seeligson and Stratton Fields

by J. D. Grigsby and D. R. Kerr. 27 p., 19 figs., 3 tables, $5.00

Oligocene-age fluvial sandstones of the Frio Formation in South Texas produce natural gas prolifically. The authors of this circular realized that identifying reservoir-quality variations that had been correlated with the presence or absence of volcanic glass detritus in the formation would have important implications for assessing resources. In the circular, the authors differentiate between Type I and Type II reservoirs in the middle Frio Formation on the basis of porosity and permeability relationships, detrital mineralogy and texture, and stratigraphic distribution. Type I reservoirs contain no volcanic glass, have a well-developed inter-

granular porosity, and have an average permeability of 36 md. In marked contrast, Type II reservoirs contain volcanic glass detritus and volcanic ash matrix, have a poorly developed intergranular pore system, and have an average permeability of 2.6 md. The instability of volcanic glass detritus within Type II reservoirs during burial and diagenesis can lead to unfavorable reservoir conditions. But because volcanic glass detritus is limited in its stratigraphic distribution, recognition of its occurrence in the subsurface not only influences reservoir assessment along the Frio gas play but also figures prominently in dividing the formation stratigraphically. Permeability thicknesses in sandstones containing volcanic glass detritus can be more than 200 times less than those of sandstones without volcanic glass detritus, net-sandstone thickness remaining constant. The authors found that the distribution of volcanic glass detritus can be identified using gamma-ray log analysis and that this analysis may also aid in resource assessment. Funding was provided by a joint venture of the Gas Research Institute under contract no. 5088-212-1718, the U.S. Department of Energy under contract no. DE-FG-2188MC25031, and the State of Texas.

GC 93-3.
Geothermal and Heavy-Oil Resources in Texas: Direct Use of Geothermal Fluids to Enhance Recovery of Heavy Oil

by S. J. Seni and T. G. Walter.
52 p., 34 figs., 6 tables, 3 appendices,
$4.75

This circular characterizes geothermal resources and medium- to-heavy-oil reservoirs in Texas, emphasizing the South Texas area, where geopressured-geothermal and medium- to heavy-oil reservoirs have been colocated. The authors evaluate the feasibility of using geothermal fluids from the Paleocene–Eocene Wilcox Group to improve ultimate oil recovery from overlying shallow, medium- to heavy-oil reservoirs of the Eocene Jackson Group. The study area covers five counties in South Texas (Duval, Jim Hogg, Starr, Webb, and Zapata Counties), where known geothermal fairways in the deep Wilcox Group lie favorably below the shallow Mirando Trend of medium- to heavy-oil reservoirs. Injection of hot, moderately fresh to saline brines will improve oil recovery by lowering viscosity and decreasing residual oil saturation. Reservoir-scale heterogeneities resulting from facies variations and diagenesis are documented in a small heavy-oil reservoir at Charco Redondo field, Zapata County. Because reservoir heterogeneities influence the productivity of both production and injections wells, understanding their origin and distribution is the key to assessing the suitability of thermally enhanced oil recovery. Funding was provided by the U.S. Department of Energy under Cooperative Agreement No. DE-FC07-85NV10412.

GC 93-4.
Comparison of Empirical Models for Calculating Vuggy Porosity and Cementation Exponent of Carbonates from Log Responses

by F. P. Wang and F. J. Lucia.
27 p., 17 figs., 1 table, 1 appendix,
$3.00

Formation evaluation in heterogeneous reservoirs is complicated by the multiplicity of pore types because acoustic properties, Archie cementation exponents, and permeability transforms differ according to pore type. In this study, undertaken as part of the Bureau of Economic Geology's Reservoir Characterization Research Laboratory research, the authors evaluate several models for estimating vuggy porosity, as well as the Archie cementation exponent from wireline logs, and present generalized models that have been developed to resolve some of the problems inherent in other models. Comparing the four models for calculating vuggy porosity from acoustic logs reveals strengths and weaknesses. The quadratic and power-law models estimate separate-vug porosity more accurately than does the Nurmi model or the Secondary Porosity Index model. The Lucia model, because it is based on point-count-derived vuggy porosity and acoustic-log response, differs greatly from other models that are based solely on acoustic-log response and is most accurate of all. The authors also review six models for calculating cementation exponents from acoustic and resistivity data and test the Lucia and Myers models against core data. Finally they present a generalized dual-porosity model for estimating cementation exponents, which is based on their review of the six models. Their dual-porosity model can be used by exploration geologists and reservoir engineers for calculating cementation exponents of carbonate rocks containing both separate and touching vugs.

Guidebook

Guidebook 26.
Guide to the Permian Reef Geology Trail, McKittrick Canyon, Guadalupe Mountains National Park, West Texas

D. G. Bebout and Charles Kerans, editors.
48 p., 46 figs.,
$8.50

The Permian Reef Geology Trail at the mouth of McKittrick Canyon, Guadalupe Mountains National Park, traverses 2,000 vertical ft (5,000 to 7,000 ft topographic elevation) of Permian (upper Guadalupian) facies through one of the world's finest examples of a rimmed carbonate platform. The present-day topography approximates that formed by the Capitan reef along the edge of the Delaware

Basin. The trail, constructed by the U.S. National Park Service in the early 1980's, provides easy access to well-exposed depositional facies and diagenetic features of this shelf margin.

This guidebook documents the stratigraphy and carbonate facies encountered along the trail by means of descriptive text, measured sections, and color photographs tied to 100-ft elevation markers. Low-altitude, oblique aerial photomosaics aid in placing the ground-level outcrop, slab, and thin-section photographs and descriptions into a regional context. Particularly helpful is the photomosaic of the north wall of McKittrick Canyon, which extends from the mouth of the canyon on the east to the windgap at the head of the canyon on the west. This photomosaic dramatically illustrates the position of the trail with respect to the total Guadalupian section exposed in the canyon, as well as the steepening depositional profile of the shelf margin, from the older Seven Rivers to the younger Tansill Formations.

This trail guide resulted from a cooperative effort by several authors—R. G. Loucks and Alton Brown, ARCO; P. M. Harris, Chevron; B. L. Kirkland, The University of Texas at Austin; Denise Mruk, Marathon; E. L. Stoudt and S. A. Longacre, Texaco; and Charles Kerans and D. G. Bebout, Bureau of Economic Geology. The trail guide, published by the Bureau of Economic Geology in September 1993, is available for purchase at the Visitor Centers of the Guadalupe Mountains and Carlsbad Caverns National Parks, as well as at the Bureau of Economic Geology.

Financial support for the trail guide was provided by ARCO Resources Technology, Carlsbad Caverns–Guadalupe Mountains Association, Chevron Petroleum Technology Company, David E. Eby, Exxon Company, U.S.A., Mobil Research & Development Corporation, Texaco E&P Technology Division, and Union Pacific Resources.

Other Publications

Atlas of Major Midcontinent Gas Reservoirs

Edited by D. G. Bebout, W. A. White, T. F. Hentz, and M. K. Grasmick.
85 p., 404 figs., 32 tables, 4 plates in pocket,
$38.00

Third in a series of atlases that began in 1989, this atlas documents principal geologic and engineering characteristics of 530 natural gas reservoirs in Oklahoma, Kansas, and northern Arkansas, each of which produced at least 10 billion cubic feet of natural gas. Diversely recorded production and engineering data from reservoirs in these states have been recast in a unified format and used to categorize reservoirs into 28 plays on the basis of geologic attributes such as lithology, geologic age, trap type, and depositional environment. Combining major reservoirs into plays provides insight into how to extend productive trends and apply new resource technology to increase supplies of natural gas. Staff from the Bureau of Economic Geology (BEG) coordinated the organization and production of this report; data were compiled as a cooperative effort of the geological surveys from the three Midcontinent states—Arkansas, Kansas, and Oklahoma. The Gas Research Institute (GRI) provided major funding for compiling data and preparing and printing the atlas; distribution costs were shared by GRI, BEG, and the Midcontinent states' geological surveys.

Also issued in 1993 were two atlas-related data bases:

Atlas of Major Midcontinent Gas Reservoirs: Data Base

by C. M. Garrett, Jr., D. G. Bebout, W. A. White, T. F. Hentz, and W. G. White.
3-p. text, 1 table, 1 disk (1.44 MB) containing ASCII and dBASE III PLUS® files,
$30.00

This data base contains engineering and production data associated with each of the 530 reservoirs described in the *Atlas of Major Midcontinent Gas Reservoirs.* Accessing these files allows the user to search, retrieve, and compare data. Production data have been updated through January 1991.

Atlas of Major Central and Eastern Gulf Coast Gas Reservoirs: Data Base

by C. M. Garrett, Jr., D. G. Bebout, W. A. White, T. F. Hentz, and W. G. White.
3-p. text, 1 table, 1 disk (1.44 MB) containing ASCII and dBASE III PLUS® files,
$38.00

This data base contains engineering and production data associated with each of the reservoirs described in the *Atlas of Major Central and Eastern Gulf Coast Gas Reservoirs.* Production data have been updated through 1992.

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

Papers

Ambrose, W. A., Levey, R. A., Vidal, J. M., Sippel, M. A., Ballard, J. R., Coover, D. M., Jr., and Bloxsom, W. E., 1993, Secondary natural gas recovery in mature fluvial sandstone reservoirs, Frio Formation, Agua Dulce field, South Texas: Gulf Coast Association of Geological Societies Transactions, v. 43, p. 11–23.

Ayers, W. B., Jr., **Kaiser, W. R.,** and Levine, J. R., 1993, Coal as source rock and gas reservoir: The University of Alabama, College of Continuing Studies, 1993 International Coalbed Methane Symposium, Short Course No. 1, 257 p.

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Services

Core Research Center

The Core Research Center (CRC) houses the largest public collection of subsurface geological materials in the United States and is open Monday through Friday from 7:00 a.m. to 5:00 p.m. (CST). Visitors may view core or cuttings in the Main Viewing Room, which is capable of displaying as much as 1,800 linear feet of conventional core.

The adjacent repository comprises approximately 103,000 square feet and 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 photography lab, thin section lab, gamma-scan facilities, sawroom, and general core re/processing. Facilities for holding core seminars are also available. Scheduling of viewing date(s) may often take as much as 4 weeks to arrange, so calls should be made well in advance of an anticipated visit to the CRC.

A brochure describing the CRC, its policies, procedures, and price list is available upon request by contacting Curator George Bush at (512) 471-1534, ext. 400. Customized printouts of CRC holdings are also available for purchase. Printouts can be generated on the basis of county, operator, lease name, or sample range, or the entire CRC data base can be generated. The Data Base Manager, Jon Boldovici, can be contacted at ext. 402.

Approximately 12,000 cores and 57,000 drill cuttings wells are available for study at the CRC. Geologic specimens housed at the CRC represent 35 countries and 1,100 counties or parishes within 43 states. Patrons are asked to provide the CRC with results of analyses of sampled materials within 1 year of completion. These studies then become part of the center's reference material.

During (fiscal) 1993, the CRC received more than 500 visitors, who made transactions involving CRC inventory that included materials from more than 1,000 wells and required the transfer of more than 15,000 boxes of core to and from viewing and shipping areas. Core processing, including slabbing and reboxing, exceeded 40,000 linear feet. The Thin Section Lab produced 2,200 thin sections, and more than 2,000 photographs were taken of geologic specimens in 1993.

New acquisitions in 1993 totaled more than 300 new cores, in excess of 4,700 boxes, and nonconventional core samples (cuttings, sidewall, unwashed cuttings, outcrop) from more than 180 wells, totaling nearly 850 boxes. Donations were received from Amoco, Anschuutz, Apache, ARCO, Bureau of Economic Geology (various projects), C. C. Company, Conoco, Core Labs, Exxon, Fina, Kerr-McGee, Lasmo Energy, Maguire Oil, Marathon, McShane Inc., Mitchell Energy, Mosbacher Energy, NASA/Lunar and Planetary Institute, Occidental, P.G. and E. Resources, Shell and Shell–Offshore, Sun, The University of Texas at Austin Department of Geological Sciences, and Unocal.

In August of 1992, the Bureau of Economic Geology took delivery of a Central Mining Equipment (CME) Model 75 drilling rig. The unit has been specially designed so that it can drill in a number of different geologic environments using various drilling techniques. In the first full year of operation, the drill rig has been used to core and install monitor wells on five different projects in environments as diverse as the Southern High Plains, the Chihuahuan Desert, the Austin Chalk, and the Texas Gulf Coast.

Mineral Studies Laboratory

The Mineral Studies Laboratory (MSL) serves as the Bureau's analytical geochemistry facility. Located in approximately 18,000 ft^2 of laboratory space adjacent to the Bureau's Research and Administrative Office, the MSL can provide nearly complete geochemical, mineralogical, and textural characterization of most geological materials. The MSL is currently staffed by Chief Chemist Steven W. Tweedy along with other professional analytical staff. The facility contains several major instrumental systems capable of performing a variety of analyses, including inductively coupled plasma optical and mass spectrometry (ICP-OES, ICP-MS) for major, minor, and trace element measurements; stable isotope mass spectrometry (hydrogen and oxygen in waters, carbon and oxygen in carbonate materials, and nitrogen in waters and ammonium compounds); electron microprobe analysis (four automated wavelength dispersive X-ray spectrometers); scanning electron microscopy (SEM) examination and photography; X-ray diffractometry (XRD) for mineral identification, thermal analysis (thermo-gravimetric analyzer); ion chromatography (IC); and gas chromatography (GC). Complete wet-chemical analysis, coal–fuel analysis, and sample comminution have also been performed at the MSL.

The MSL provided analytical services on many Bureau research projects during 1993. These include Characterization of the Pantex Plant, Texas Low-Level Radioactive Waste Disposal Authority—Eagle Flat (LLEF), Canadian River, Superconducting Super Collider—Hydrology (SSC), Texas Advanced Research Program—Primitive Atmospheres (SRP-ATM), Reservoir Characterization Research Laboratory, San Andres and Grayburg (SAGRAY), State Lands Energy Resources Optimization (SLERO), Trinity River, Attorney General, and Nitrogen Isotopes projects. In addition to supporting Bureau projects, the MSL provided services to the following University of Texas at Austin departments: Mechanical Engineering, Center for Transportation Research, and Texas Archeological Research Laboratory. The MSL also provided services to Sandia National Laboratories during 1993.

The MSL continues to develop in areas of stable isotope studies, quality assurance, and laboratory determinations unique to hydrology. The laboratory routinely participates in EPA's Water Pollution Laboratory Performance Evaluation Studies.

Public Information

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

Extensive data and information are available at the Bureau's Reading Room/Data Center, and members of the Bureau's research staff provide advisory and technical services in their areas of expertise. The Bureau's Public Information Geologist maintains files on mineral resources (both energy and nonenergy minerals) and general geology of specific areas of the State and assists patrons in locating answers to questions. During 1993, approximately 1,500 such requests were handled by L. Edwin Garner, Public Information Geologist.

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 50 periodicals. Included in the collection are extensive reports and open-file materials received from the U.S. Geological Survey, the U.S. Bureau of Mines, and the U.S. Department of Energy.

The Data Center houses an extensive collection of surface and subsurface geological data pertaining to Texas and adjacent states. Research Document Inventory data consisting of original maps, cross sections, and other data used in preparing Bureau publications are available. Subsurface data files include well logs for more than 50,000 wells in Texas and 8,000 wells in adjacent states; microfiche copies of well logs for more than 40,000 wells in West Texas, New Mexico, and Oklahoma; scout tickets and well records for more than 200,000 Texas wells and 30,000 New Mexico wells; driller's logs for about 400,000 Texas wells; and completion cards for more than 300,000 Texas wells and more than 150,000 wells in adjacent states.

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

Geophysical Log Facility

The Geophysical Log Facility (GLF), managed by L. Edwin Garner, is housed in the Bureau's Reading Room/Data Center. The facility was established by State legislation, effective September 1, 1985, that requires that all operators of oil, gas, and geothermal wells provide the Railroad Commission of Texas with at least one copy of a well log for each new, deepened, or plugged well. A subsequent agreement with the Railroad Commission designated the Bureau as the entity responsible for providing public access to these logs. The Railroad Commission supplies paper or microfiche copies of the well logs and three different cumulative indexes to the logs. They are then filed at the GLF by district number and API number. Users of the facility include commercial companies, independent researchers, and Bureau scientists. Patrons may examine well logs using the GLF's microfiche readers. Requests for log copies can be made in person or by mail or telephone.

By the end of 1993, the facility had accumulated approximately 90,000 well logs of various types, at a rate of 800 logs per month, which are being entered into the GLF's computer data base.

Highlights

Awards and Honors

Bureau scientists won several awards for presentations given at the 1992 annual meeting of the Gulf Coast Association of Geological Societies. **Kenneth T. Barrow** won the Best Paper Award for his paper titled "Shaly Sand Analysis as an Indicator of Hydrocarbon Production Potential in the Olmos Formation, Las Tiendas Trend, South Texas." The second-place award went to **Raymond A. Levey** and coauthors **Robert J. Finley** and **Richard P. Langford** for their paper titled "Stratigraphic Compartmentalization within Gas Reservoirs: Examples from Fluvial-Deltaic Reservoirs of the Texas Gulf Coast." **J. Ulises Ricoy** and coauthors **Joseph S. Yeh** and **Richard P. Major** won third place for their paper titled "Evaluation of Reserve-Growth Potential in Barrier/Strandplain Compartmentalized Reservoirs of the Frio Formation, Lavaca Bay Field, South Texas."

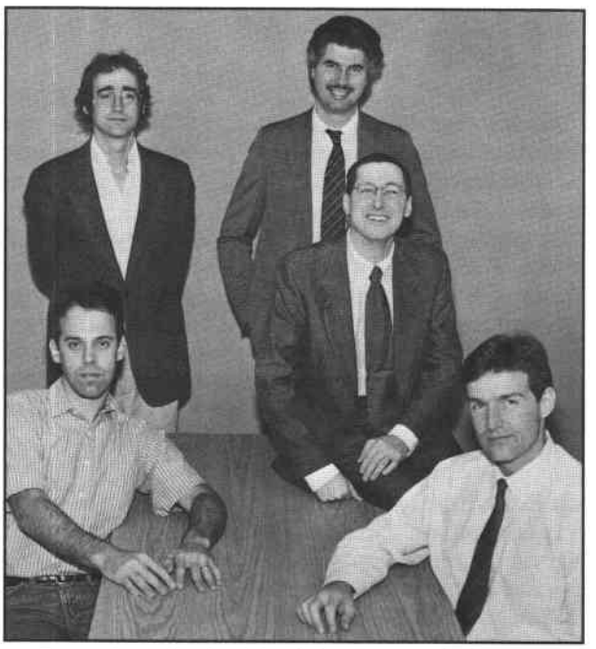
Virgil E. Barnes, recipient of the American Association of Petroleum Geologists' Public Service Award for 1993. Photograph by David M. Stephens.

The West Texas Geological Society awarded Bureau scientists first-place honors for presentations made at the society's 1992 Annual Fall Symposium. Best Oral Presentation went to **Richard P. Major** and coauthor **Mark H. Holtz** for their paper titled "Calibration of Porosity Logs and Delineation of Flow Units in a San Andres Reservoir: Keystone Field, West Texas." **Charles Kerans** and coauthor **Michael H. Gardner** won Best Poster Presentation for "Styles of Sequence Development within Uppermost Leonardian through Guadalupian Strata of the Guadalupe Mountains, Texas and New Mexico."

Bureau scientists were also honored by receiving a variety of other awards and recognition. **Virgil E. Barnes** received the Public Service Award from the American Association of Petroleum Geologists (AAPG) at the association's 1993 annual meeting. He was cited "for distinguished contributions to the science and profession of geology and for dedicated, unparalleled public service to Texas and the nation." **F. Jerry Lucia** was awarded the Distinguished Service Award from the West Texas Geological Society. **Richard P. Major** was named a Fellow of the Geological Society of America. **Roger Tyler** and coauthors **Stephen E. Laubach** and **William A. Ambrose** were the recipients of the AAPG Energy Minerals Division Best Paper Award for their paper titled "Face-Cleat Patterns in Rocky Mountain Foreland Basins, Western United States: Permeability Indicators for Coalbed Methane" presented at the 1992 AAPG Rocky Mountain Section meeting. In recognition of one of the Best Papers of 1992 published in *Geophysics*, the Society of Exploration Geophysicists awarded honorable mention to **Bob A. Hardage** for his article titled "Radiation Patterns and Seismic Waves Generated by a Roller-Cone Drill Bit." **Charles Kerans** received Best Poster Award for his presentation of "Relative Sea-Level Record of Yates and Tansill Formation Shelf Facies, Permian Reef Geology Trail: Implications for Platform Development," given at the 1993 annual meeting of the Southwest Section AAPG.

New Research Staff

David L. Carr joined the Bureau as a Research Scientist Associate to work on the Secondary Natural Gas Recovery project. Carr received his M.A. in geology from The University of Texas at Austin and has worked as a petroleum geologist for Tenneco Oil Company, studied marine geology at James Cook University in Queensland, Australia, and worked as a Denver-based consulting geologist in reservoir characterization and coalbed methane production. **Bruce A. Desselle** came to the Bureau as a Research Scientist Associate to work on the Gulf Coast Oil and Gas Atlas projects. Desselle, after receiving his M.S. from the University of Southwestern Louisiana, worked as a micropaleontologist for Texaco



Research staff who joined the Bureau during 1993 (clockwise): Bruce A. Desselle, Brian J. Willis, Giovanni Guglielmo, Jr., Paul R. Knox, and David L. Carr. Photograph by David M. Stephens.

and a consulting paleontologist for Paleo-Data, Inc., in New Orleans. **Giovanni Guglielmo, Jr.**, a Research Fellow at the Bureau, received his Ph.D. from The University of California at Santa Cruz before he became a post-doctoral fellow at The University of California at Santa Barbara. During this time, he performed field and three-dimensional computer modeling studies of granite diapirs and tectonic deformation. As a researcher in the Bureau's Applied Geodynamics Laboratory, Guglielmo is active in computer visualization of salt diapirs and associated oil traps. **Paul R. Knox** joined the Bureau as a Research Associate to work on the State Lands Resource Optimization (SLERO) project. Knox received his M.S. from California State University at Long Beach and has several years' industry experience, having worked for UNOCAL Corporation on development and exploration projects in all of the major California onshore basins. **Brian J. Willis** joined the Bureau to work on the Deltaic Reservoirs Industrial Associates project, following a research fellowship at the Department of Paleobiology of the Smithsonian Institution. Willis received his Ph.D. from the State University of New York, Binghamton, where he studied depositional and tectonic controls on Miocene fluvial deposits exposed in the Himalayan foredeep basin of northern Pakistan.

Research Staff Activities

Lectures and Public Addresses

Arten J. Avakian

"Minerals, rocks, and fossils": presented to kindergarten classes of Mathews Elementary School, Austin, Texas.

"Geology of Northwest Park, Austin, Texas": presented to children and adults of the Austin Area Homeschoolers Association, Northwest Park, Austin, Texas.

Roger J. Barnaby

"Reservoir characterization of Red Fish Bay field": presented to the State Lands Energy Resources Optimization Project 1993 annual review meeting, Austin, Texas.

Kenneth T. Barrow

"Las Tiendas (Olmos) field reservoir characterization": presented to the State Lands Energy Resources Optimization Project 1993 annual internal review meeting, Austin, Texas.

"Powderhorn (Miocene) field reservoir characterization": presented to the State Lands Energy Resources Optimization Project 1993 annual internal review meeting, Austin, Texas.

Don G. Bebout

"Ooid-grainstone shoals, Joulters Cays, Bahamas: a modern analog of carbonate hydrocarbon reservoirs": presented to the South Texas Geological Society, San Antonio, Texas.

Mark J. Burn

"Linked diapir and growth-fault kinematics in outcrop": presented to Applied Geodynamics Laboratory Industrial Associates, Austin, Texas.

David L. Carr

"Preliminary geologic results of the Bend Conglomerate reservoir characterization, Boonsville field, North-Central Texas": presented to Arch Petroleum, Inc., Fort Worth, Texas, and Enserch Exploration, Inc., Bridgeport, Texas.

Sigrid J. Clift

"Careers in geology": presented to Lago Vista High School Career Exploration classes, Lago Vista, Texas.

Bruce K. Darling

"Recharge processes and pathways in southern Hudspeth County, Texas": presented to the Citizens Advisory Committee for the Texas Low-Level Radioactive Waste Disposal Authority, Sierra Blanca, Texas.

"Ground-water hydrology of Hudspeth County, Texas": presented to the Citizens Advisory Committee for the Texas Low-Level Radioactive Waste Disposal Authority, Sierra Blanca, Texas.

"Tracing regional ground-water flow paths from geochemical and isotopic signatures": presented to the Texas Low-Level Radioactive Waste Disposal Authority and Dames and Moore, Inc., Austin, Texas.

"Ground-water age dating methods": presented to the Citizens Advisory Committee for the Texas Low-Level Radioactive Waste Disposal Authority, Sierra Blanca, Texas.

"Ground-water chemistry of Eagle Flat and surrounding area": presented to the Citizens Advisory Committee for the Texas Low-Level Radioactive Waste Disposal Authority, Sierra Blanca, Texas.

Alan R. Dutton

"Hydrogeologic studies for site characterization: case study of ground-water flow in the Austin Chalk at the Superconducting Super Collider site, North Texas": presented to the Association of Desk and Derrick Clubs, Petroleum Extension Service, The University of Texas at Austin, Austin, Texas.

"Sources and ages of ground water in confined and unconfined aquifers beneath the U.S. High Plains": presented to Department of Geology, Baylor University, Waco, Texas, and to the Department of Geoscience, University of Houston, Houston, Texas.

"Hydrogeologic investigations of regional ground-water flow and ground-water resources, Ellis County area, North Texas": project briefing presented to the Texas National Research Laboratory Commission and Superconducting Super Collider Laboratory, DeSoto, Texas.

Shirley P. Dutton

"Porosity preservation by early siderite cementation in Canyon sandstones, Val Verde Basin, West Texas": presented to Department of Geology, Baylor University, Waco, Texas.

"Oil and gas reservoir characterization research at the Bureau of Economic Geology, Texas": presented to the First Annual Historically Black Colleges and Universities–Private Sector–Fossil Energy Research and Development Technology Transfer Symposium, New Orleans, Louisiana.

"Revitalizing a mature oil play: strategies for finding and producing unrecovered oil in Frio fluvial-deltaic reservoirs of South Texas": presented to the U.S. Department of Energy Oil Program Contractor Review Meeting, Fountainhead, Oklahoma.

"Comparison of diagenesis of Fall River sandstone in outcrop and subsurface": presented to the annual fall meeting of the Deltaic Industrial Associates Group, Hot Springs, South Dakota.

"Assessing the continuity of geologic strata: the Gypsy Test Site": presented to the 1993 Project Advisor Group Meeting, Gas Research Institute, Houston, Texas.

"Oil reservoir characterization research at the Bureau of Economic Geology:" presented to Siberian Oil and Gas Interns, Austin, Texas.

Robert J. Finley

"New directions in natural gas reservoir development: integrating geology, engineering, geophysics and petrophysics": presented to the Society of Independent Professional Earth Scientists, Austin, Texas.

"Improved recovery from complex gas reservoirs and tight gas sandstones": presented to Improved Oil & Gas Recovery Workshops sponsored by Texas Independent Producers and Royalty Owners Association and the Bureau of Economic Geology, Dallas, Texas; Amarillo, Texas; and Houston, Texas.

"Reserve appreciation in existing fields: joint venture project overview and status" and "Project summary": presented to the 1993 Project Advisor Group Meeting, Gas Research Institute, Golden, Colorado.

"Natural gas resource programs": presented to the Desk and Derrick Club, Austin, Texas.

"Integrated geological and geophysical characterization of Gulf Coast reservoirs for incremental natural gas discovery": presented to the Corpus Christi Geological Society, Corpus Christi, Texas.

"Infill development": presented to the Natural Gas Wellhead Deliverability Over the Intermediate Term Workshop sponsored by the Electric Power Research Institute, Houston, Texas.

R. Stephen Fisher

"Sandstone mineralogy and permeability in a sequence stratigraphic framework: the Ferron Sandstone (Cretaceous), central Utah": presented to Deltaic Reservoirs Industrial Associates Annual Review Meeting, Austin, Texas.

"Use of nitrogen isotopes in tracing nonpoint pollution sources": presented to the Texas Institute for Applied Environmental Research, Soil Conservation Service, and Blacklands Research Center, Temple, Texas.

"Overview of the Bureau of Economic Geology groundwater characterization program in Erath and surrounding counties": presented to the Texas Institute for Applied Environmental Research, Soil Conservation Service, and Blacklands Research Center, Temple, Texas.

"Hydrogeochemical and production controls on naturally occurring radioactive materials in oil- and gas-field operations": presented to the Department of Energy Annual Contractors Review Meeting, Fountainhead, Oklahoma.

"Characterization and quantification of geologic and petrophysical heterogeneity in fluvial-deltaic reservoirs": presented to the Gas Research Institute Geoscience Contractor Review Meeting, Houston, Texas.

"Results of 3-year Ferron outcrop characterization to improve natural gas sandstone reservoir models": presented to the Gas Research Institute Geoscience Contractor Review Meeting, Houston, Texas.

William L. Fisher

"Natural gas in the U.S.—will supplies be there when needed?": presented at the Canadian Energy Research Institute North American Natural Gas Conference, Calgary, Alberta, Canada.

"Directions in science and geoscience policy": presented to the Board of Earth Sciences and Resources, National Academy of Sciences, Washington, D.C.

"The newly emerging domestic oil and gas industry": presented to the Ohio Oil and Gas Association, Winter Meeting, Columbus, Ohio.

"U.S. oil, gas, and geologists: looking forward": presented to the Society of Independent Earth Scientists Annual Meeting, San Antonio, Texas.

"Geologists and the environment: the academic view": presented to the American Association of Petroleum Geologists Annual Meeting, New Orleans, Louisiana.

"Future of the U.S. energy and mineral resource industry": presented to the Society of Independent Earth Scientists, Futures Conference, Houston, Texas.

"U.S. natural gas: reserves and supplies": presented to the Aspen Institute Policy Issue Forum on Energy, Environment, and the Economy, Aspen, Colorado.

"Geology and resources: future direction": presented to the Nebraska Geological Survey Centennial Celebration, Lincoln, Nebraska.

"What's left of traditional energy resources in Texas, gas supplies, and resources": presented to the Symposium, "Toward a Texas Energy Policy," Partners in Policy Forum IV, Austin, Texas.

"Opportunities in domestic oil and gas": presented to the Shreveport Geological Society, Shreveport, Louisiana.

Robert L. Folk

"Bacteria and nannobacteria and mineral precipitation": presented to the Departments of Geology and Marine Science, University of Miami, Coral Gables, Florida.

"Are Egyptian pyramids made out of concrete?": presented to the Departments of Geology and Marine Science, University of Miami, Coral Gables, Florida.

"L'attivita della batterie chi stanno facendo cristallizzazzione dei minerali diversi: carbonati, selfidi, silicati, ecc. nelle sorgenti idrotermali di Viterbo ed in tutto il mondo": presented to the Dipartimento di Geologia, Universita di Bari, Bari, Italy.

"Bacteria and nannobacteria precipitating carbonate minerals in Hot Springs of Le Zitelle, Viterbo, Italy": presented to the International Congress of Geomorphology, Hamilton, Ontario, Canada.

Alan E. Fryar

"Experimental modeling of diagenetic fronts in a contaminated sand aquifer": presented to the Department of Geological Sciences, Texas A&M University, College Station, Texas, and to INTERA, Inc., Austin, Texas.

William E. Galloway

"Slope and basin depositional systems": presented to the National Centre for Petroleum Geology and Geophysics, University of Adelaide, Adelaide, Australia.

Michael H. Gardner

"Regional variations in stratal geometry and facies architecture of mid-Cretaceous depositional sequences, central western interior foreland basin of North America" and "Sediment volume partitioning in facies tracts: a primary control on the stratal geometry of depositional sequences": presented to the Department of Geological Sciences, Northwestern University, Evanston, Illinois, and (the latter only) to Chevron U.S.A. Production Company, Houston, Texas.

"Sequence stratigraphy and facies architecture of the Upper Cretaceous Ferron Sandstone, east-central Utah": presented to the Department of Geological Sciences, The University of Texas at Austin, Austin, Texas.

"Reservoir characterization of Delaware Mountain Group reservoirs: Screw Bean field area, Delaware Basin, West Texas": presented to the State Lands Energy Research Optimization Project 1993 annual review meeting, Austin, Texas.

"Holistic sequence stratigraphy: bridging the gap between seismic stratigraphy and sedimentology": presented to the Institute of Geophysics, The University of Texas at Austin, Austin, Texas, and to Chevron U.S.A. Production Company, Houston, Texas.

"The compound effect of multiple scales of cyclicity on hydrocarbon seals in sand-rich deep-water systems: Delaware Mountain Group (Permian, Guadalupian), West Texas": presented to the West Texas Geological Society, Midland, Texas.

"Hydrocarbon habitat in the Permian (Guadalupian) Delaware Mountain Group, Delaware Basin, West Texas": presented to Conoco Oil Company, Midland, Texas, to the Roswell Geological Society, Roswell, New Mexico, and to Ensign Oil Company, Denver, Colorado.

"The tale of two margins: contrasting stratal geometry and facies architecture of fluvial-deltaic strata from high and low accommodation settings, Upper Cretaceous Ferron Sandstone, east-central Utah, and Lower Cretaceous Fall River Formation, eastern Wyoming and western South Dakota," and "Using sequence stratigraphy to understand hydrocarbon habitat in Permian (Guadalupian) Delaware Mountain Group Reservoirs, Delaware Basin, West Texas": presented to Chevron U.S.A. Production Company, Houston, Texas.

Giovanni Guglielmo, Jr.

"Progress in computer visualization": presented to the Applied Geodynamics Laboratory Industrial Associates, Austin, Texas.

Thomas C. Gustavson

"Playa sediments, soils, and paleosols: keys to processes affecting recharge to the Ogallala aquifer, Texas High Plains": presented at the Soil Survey and Land Resource Workshop, College Station, Texas.

"Tertiary and Quaternary stratigraphy and paleoclimate of the Southern Great Plains, Texas and New Mexico": presented to Department of Geography (Geography 386C), The University of Texas at Austin, Austin, Texas.

"Ogallala Formation and the perched aquifer": presented to the Amarillo Area Office–Public Information Coordinating Group, U.S. Department of Energy, Amarillo, Texas.

"The Neogene Ogallala and Quaternary Blackwater Draw Formations: geology and water resource issues on the Southern High Plains": presented to the Environmental Sciences Section, Southwest and Rocky Mountain Divisions, American Association for the Advancement of Science, Albuquerque, New Mexico.

"Tertiary–Quaternary Ogallala and Blackwater Draw Formations, Texas and New Mexico": presented to the Austin Geological Society, Austin, Texas.

Douglas S. Hamilton

"Reservoir characterization of Seventy-Six West and Colmena–Cedro Hill fields": presented to the State Lands Energy Resources Optimization Project, 1993 annual internal review meeting, Austin, Texas.

"Deeper pay potential in the Duval County Ranch Corporation area": presented to the State Lands Energy Resources Optimization Project 1993 annual internal review meeting, Austin, Texas.

"Geological heterogeneity and potential for advanced secondary recovery of oil by geologically-targeted infill drilling in barrier/strandplain reservoirs: the Jackson–Yegua Barrier/Strandplain Sandstone play, South Texas": presented to the Department of Geosciences, Soft Rock Seminar, The University of Texas at Austin, Austin, Texas.

H. Scott Hamlin

"Tight gas case studies: lessons from Frontier stratigraphic studies": presented to Gas Strategy Team, Chevron U.S.A., Austin, Texas.

Bob A. Hardage

"3-D seismic imaging of heterogeneous gas reservoirs": presented to the San Antonio Geophysical Society, San Antonio, Texas.

"3-D seismic imaging of compartmented reservoirs": presented to the West Texas Geological Society, Midland, Texas.

"Onshore 3-D seismic case histories": presented to Kansas independent producers, 3-D seismic seminar, Kansas Geological Society, Wichita, Kansas.

"Applications of borehole geophysics": presented to the 1993 Annual Archie Conference, Houston, Texas.

"3-D seismic imaging of South Texas fluvial gas reservoirs": presented at SIPES monthly meeting, San Antonio, Texas.

"GRI-sponsored geophysical activity at the Bureau of Economic Geology": presented to the Geophysical Technical Committee, Gas Research Institute, Chicago, Illinois.

"Integrating geophysical, geological, and engineering models of heterogeneous reservoirs": presented to the Society of Exploration Geophysicists Development and Production Forum, Osage Beach, Missouri.

"Overview of geophysical technology": presented to the Texas State Bar, Dallas, Texas.

Tucker F. Hentz

"Sequence stratigraphy of the Middle to Upper Pennsylvanian Cleveland and Marmaton siliciclastics, western Anadarko Basin, Texas Panhandle": presented to the North Texas Geological Society, Wichita Falls, Texas.

Barry J. Hibbs

"Physical hydrogeology of Eagle Flat and surrounding areas": presented to the Texas Low-Level Radioactive Waste Disposal Authority and Dames and Moore, The University of Texas at Austin, Bureau of Economic Geology, Austin, Texas.

"Surface electrical resistivity applied to shallow hydrogeologic investigations": presented to the Texas Low-Level Radioactive Waste Disposal Authority and Dames and Moore, Phoenix, Arizona.

Mark H. Holtz

"Play analysis and resource assessment of reservoirs for which the State of Texas holds royalty interest": presented at the State Lands Energy Resources Optimization Project 1993 annual internal review meeting, Austin, Texas.

"Reservoir engineering characteristics of the Leonardian restricted platform carbonate oil reservoirs, West Texas": presented to the West Texas Chapter, Society of Petroleum Engineers, Midland, Texas.

"Geologic hydrocarbon plays in Texas: definitions and distributions": presented to the Branch of Petroleum Geology, U.S. Geological Survey, Denver, Colorado.

"Resource assessment of Texas State Lands": presented at the Symposium on New Oil and Gas Recovery Technologies Targeted for West Texas Hydrocarbon Reservoirs, West Texas Geological Society and Bureau of Economic Geology, Midland, Texas.

"Production and reserve characteristics of Leonardian restricted platform carbonate reservoirs, West Texas": presented at the Symposium on New Oil and Gas Recovery Technologies Targeted for West Texas Hydrocarbon Reservoirs, West Texas Geological Society and Bureau of Economic Geology, Midland, Texas.

Susan D. Hovorka

"Austin Chalk at the SSC site—cyclic sedimentation, synsedimentary volcanism, microfabrics, and fracture intensity": presented to Union Pacific Resources, Fort Worth, Texas.

Martin P. A. Jackson

"Fault systems of salt tectonics": presented to the East Texas Geological Society, Tyler, Texas.

"Role of regional extension in salt tectonics" and "Superposed contraction of extensional diapiric systems": presented to TOTAL S. A., Paris, France.

"Overview of Applied Geodynamics Laboratory research for 1993," "Role of raft tectonics in Angolan petroleum systems," "Role of progradation in emplacement of salt sheets," and "Applied Geodynamics Laboratory research directions for 1994": presented to Applied Geodynamics Laboratory Industrial Associates, Austin, Texas.

Mary L. W. Jackson

"Structural history of the Sabine Arch and its relation to hydrocarbon traps": presented to the Shreveport Geological Society, Shreveport, Louisiana.

William R. Kaiser

"Geology and hydrology of coalbed methane in the Greater Green River Basin": presented to the Gas Research Institute, Natural Gas Supply Project Advisors Group Meeting, Dallas, Texas.

Charles Kerans

"The geologic framework and reservoir characteristics of the San Andres Formation: integration of outcrop and subsurface data": presented to Mobil Producing Company, Midland, Texas.

"The sequence framework of San Andres reservoirs from outcrop, core, and seismic data": presented to ARCO, Midland, Texas.

"Characterization of carbonate ramp reservoirs: developing a sequence framework for petrophysical quantification": presented to the Geological Society of London—Carbonate Reservoirs: Models for Exploration and Development, London, England.

"Developing a sequence framework for petrophysical quantification, San Andres Formation, West Texas": presented to TOTAL, Paris; British Petroleum Company, London; Shell (KSEPL), Rijswijk, Holland.

"Outcrop framework for reservoir modeling, San Andres Formation of the Permian Basin, West Texas and New Mexico": presented at the University of Houston Seminar Series, Houston, Texas.

"Carbonate platform development and implications for sequence stratigraphic framework of the Frasnian": presented to Amoco Production Company, Sequence Stratigraphy Seminar Series, Houston, Texas.

"The stratigraphic framework of the Grayburg Formation, eastern margin of Central Basin Platform": presented at San Andres–Grayburg Reservoir Characterization Research Laboratory review meeting, Carlsbad, New Mexico.

"Quantitative analysis of distribution of grainstone bar complexes in Guadalupian (Permian) carbonate ramp systems of the San Andres and Grayburg Formations; towards a foundation for object modeling": presented at San Andres–Grayburg Reservoir Characterization Research Laboratory review meeting, Carlsbad, New Mexico.

Paul R. Knox

"Reservoir characterization of West Fulton Beach field": presented to the State Lands Energy Resources Optimization Project 1993 annual internal review meeting, Austin, Texas.

Richard P. Langford

"Fissures in the Trans-Pecos area": presented to the Citizens Advisory Committee for the Texas Low-Level Radioactive Waste Disposal Authority, Sierra Blanca, Texas.

"Geomorphology and surficial stratigraphy of the Texas low-level radioactive waste isolation facility": presented to the Texas Low-Level Radioactive Waste Disposal Authority, Dames and Moore, Inc., Radian Corporation, and Morrison Knudsen, Inc., Santa Fe, New Mexico, and Austin, Texas.

Stephen E. Laubach

"Summary of issues pertaining to detection and characterization of fractures in the subsurface": presented to the Gas Research Institute–Bureau of Economic Geology Natural Fracture Workshop, Austin, Texas.

"Current issues in structural research in the petroleum industry": presented to ARCO Exploration and Production Company, Plano, Texas.

"Fracture patterns in Cretaceous sandstone outcrops of the western United States—are they representative of those in reservoirs?": presented to ARCO Exploration and Production Company, Plano, Texas.

"Natural fractures in Cretaceous sandstones of the western United States: profiting from a widespread reservoir element": presented to the Gas Research Institute–U.S. Department of Energy Greater Green River Basin Natural Gas Technology Workshop, Denver, Colorado.

"A new national report on geology and engineering aspects of tight gas sandstones": presented to the Gas Research Institute Project Advisors Group meeting, Oklahoma City, Oklahoma.

"Natural fractures in Sonora Canyon sandstones, Sonora and Sawyer fields, Sutton County, Texas": presented to the 1993 Society of Petroleum Engineers Rocky Mountain Regional and Low-Permeability Reservoir Symposium, Denver, Colorado.

Raymond A. Levey

"Case studies demonstrating the economics of secondary gas recovery in natural gas reservoirs in the Gulf Coast": presented to the Gas Research Institute, Project Advisors meeting, Denver, Colorado.

"Analysis of integrated geologic, geophysical, and engineering data for identifying secondary gas in Stratton field": presented to Union Pacific Resources, Austin, Texas.

"Research applications of oil and gas reservoir characterization conducted by the Bureau of Economic Geology": presented to the Gypsy Partners Meeting, University of Oklahoma, Norman, Oklahoma.

"The Secondary Natural Gas Recovery Project": presented to British Petroleum, Austin, Texas.

"Gas reservoir characterization research": presented to Siberian Oil and Gas Interns, Austin, Texas.

"Technical results and economic benefits of the SGR Project: Gulf Coast case": presented to the GRI–DOE Technical Advisory Committee for the Infield Reserve Growth Joint Venture Project, Austin, Texas.

"Objectives of natural gas supply research and results from the Secondary Gas Recovery Project conducted by the Bureau of Economic Geology for the Gas Research Institute and the U.S. Department of Energy": presented to Trident NGL, Inc., The Woodlands, Texas.

"Integrated geologic, geophysical, and engineering analysis for maximizing secondary gas recovery": presented to Halliburton Geophysical Services, Austin, Texas.

"Research results from the Gulf Coast in natural gas supply and objectives of secondary gas recovery in Midcontinent sandstones": presented to Arch Petroleum, Inc., and Threshold Development, Inc., Fort Worth, Texas.

"Targeted technologies for infield reserve growth: research objectives of the secondary gas recovery project in Midcontinent sandstones": presented to Waggoner–Baldridge Energy Company, Dallas, Texas.

"Secondary gas recovery research in Boonsville field in North-Central Texas": presented to OXY USA, Inc., Mitchell Energy Corporation, and Enserch Exploration, Inc., Austin, Texas.

"Research objectives of the Secondary Gas Recovery project in Midcontinent sandstones": presented to Potts Stevens Energy Company and Kerr-McGee Corporation, Oklahoma City, Oklahoma.

"Future research directions and opportunities for industry cooperation in the GRI–DOE Midcontinent Secondary Natural Gas Recovery project; targeted technology applications for infield reserve growth": presented to the Exploration Managers meeting, Oklahoma City, Oklahoma.

"Results from the Secondary Gas Recovery research project to maximize infield reserve growth: future opportunities for industry cooperation in the GRI–DOE Midcontinent region": presented to the Oklahoma City Geological Society, Oklahoma City, Oklahoma.

"Techniques and strategies for maximizing natural gas recovery in fluvial and deltaic reservoirs in the Gulf Coast: targeted technology applications for infield reserve growth": presented to the Houston Chapter, Society of Professional Earth Scientists, Houston, Texas.

F. Jerry Lucia

"Quantification of sequence stratigraphic framework, carbonate ramp reservoirs, San Andres Formation, Permian Basin, Texas and New Mexico, U.S.A.": presented to BP International, Limited, London, England; Shell Exploration and Production Laboratory, Rijswijk, The Netherlands; and TOTAL Exploration and Production, Paris, France.

"Myths and fantasies about porosity and unconformities": presented to the AAPG Hedberg Research Conference, Vail, Colorado.

"Carbonate rock fabric units, the key to converting geologic observations into petrophysical parameters for reservoir simulation": presented to ARCO, Midland, Texas.

"Quantification of geologic framework—Algerita Escarpment and Seminole field": presented to Mobil, Midland, Texas.

"Quantification of carbonate-ramp reservoirs, Algerita Escarpment and Seminole field": presented to Amoco Oil and Gas Company, Houston, Texas.

"Reservoir characterization of San Andres outcrops, Algerita Escarpment, New Mexico": presented to ARCO Exploration and Production Technology, Plano, Texas.

"Quantification of carbonate-ramp reservoir models": presented to sponsors of the San Andres–Grayburg Reservoir Characterization Research Laboratory, Austin, Texas.

Richard P. Major

"Evaluation of multiple compartmentalized reservoirs in barrier/strandplain facies of the Frio Formation, Lavaca Bay field, South Texas": presented to the Corpus Christi Geological Society, Corpus Christi, Texas.

"Reservoir characterization of Keystone field": presented to the State Lands Energy Resources Optimization Project 1993 annual internal review meeting, Austin, Texas.

"Geochemical indicators of the origins and pathways of dolomitizing fluids and their effects on porosity and permeability: examples from Bonaire, Netherlands Antilles": presented to the Austin Geological Society, Austin, Texas, to SEPM (Society for Sedimentary Geology), Permian Basin Section, Midland, Texas, and to the Austin Chapter, Association of Women Geoscientists, Austin, Texas.

Lee E. McRae

"Research objectives and strategies for reservoir characterization of mature Frio fluvial-deltaic sandstone reservoirs in South Texas": presented to Conoco Oil Company, Corpus Christi, Texas.

"Strategies for finding and producing unrecovered oil in mature Frio fluvial-deltaic sandstone reservoirs in South Texas": presented to Mobil Exploration and Producing U.S. Oil Company, Houston, Texas.

Auburn L. Mitchell

"Background and border activities of the Bureau of Economic Geology": presented to the U.S. Environmental Protection Agency Border Ground-Water Protection Subgroup meeting, Las Cruces, New Mexico.

Robert A. Morton

"Beach stability and options for beach replenishment and dune restoration on South Padre Island": presented to the Beach and Dune Task Force, South Padre Island, Texas.

"Geologic and oceanographic issues related to Coastal Zone management in Texas": presented to the Department of Ocean Engineering, Texas A&M University, College Station, Texas.

William F. Mullican III

"The role of playa lakes on the formation of perched aquifers": presented to the U.S. Department of Energy's Quarterly Public Meeting on Environmental Restoration Program at the Pantex Plant, Amarillo, Texas.

"Unsaturated zone hydrology of the Eagle Flat site": presented to the Texas Low-Level Radioactive Waste Disposal Authority Design Conference, Santa Fe, New Mexico.

"The role of playas on recharge to the Ogallala aquifer in the Southern High Plains": presented to the Texas Water Commission, District 1, Symposium on Waste Water Discharge to Playas, Amarillo, Texas.

"An overview of the Bureau's Pantex Project, with emphasis on hydrologic characterization and the role of playas on recharge to the Ogallala aquifer in the Southern High Plains": presented to the Texas Water Commission, Austin, Texas.

"Instrumentation and performance of pumping tests": presented to the Department of Geological Sciences (Geology 382), The University of Texas at Austin, Austin, Texas.

"Design, construction, and completion of monitor wells at hazardous waste sites": presented to the Department of Geological Sciences (Geology 382), The University of Texas at Austin, Austin, Texas.

H. Seay Nance

"Status of fracture mapping at the SSC site": presented to the Texas National Research Laboratory Commission and SSC Laboratory, DeSoto, Texas.

Jeffrey G. Paine

"Seismic investigations at the proposed low-level radioactive waste repository, Hudspeth County, Texas": presented at the Low-Level Radioactive Waste Disposal Authority Project Characterization Review Meeting, Austin, Texas.

"Shallow seismic methods in environmental and hydrogeological studies": presented to the Department of Geological Sciences (GEO368K), The University of Texas at Austin, Austin, Texas.

"Environmental and groundwater geophysics: shallow reflection surveying and electromagnetic methods": presented to the Department of Geological Sciences (GEO376L), The University of Texas at Austin, Austin, Texas.

Jay A. Raney

"Overview of geologic and hydrologic characterization studies, Faskin Ranch, Hudspeth County, Texas": presented to the Texas Low-Level Radioactive Waste Disposal Authority, Texas Water Commission, and engineering contractors, Austin, Texas.

"Development of a geologic atlas for the Rio Grande–Rio Bravo basin": presented to the Rio Grande–Rio Bravo GIS Consortium, Austin, Texas.

"Site characterization activities and geologic and hydrologic setting of the Eagle Flat study area, Hudspeth County, Texas" (lecture and field trip): presented to the Maine State Geologist and representatives of the Maine Low-Level Radioactive Waste Authority, Hudspeth County, Texas.

"Results of regional and site-specific characterization studies, proposed Faskin Ranch site, Hudspeth County, Texas" (lecture and field trip): presented to a technical review team for the State of Vermont, Sierra Blanca, Texas.

Stephen C. Ruppel

"Geological characterization of a complex restricted platform carbonate reservoir, Monahans field, West Texas": presented at New Oil and Gas Recovery Technologies Targeted for West Texas Hydrocarbon Reservoirs Symposium, Midland, Texas.

"Effects of sea-level fall on porosity and permeability development in shallow-water platform carbonates, West Texas": presented to the West Texas Geological Society, Midland, Texas, and the American Association of Petroleum Geologists Hedberg Research Conference, Vail, Colorado.

"Geological characterization of Monahans field": presented to Shell Western Exploration and Production Company, Houston, Texas.

Carol L. Ruthven

"An assessment of the oil resource base of the United States": presented at the Global Energy and Environmental Matters Conference, Keystone, Colorado.

Bridget R. Scanlon

"Evaluation of recharge rates using chemical tracers at low-level radioactive waste disposal sites in the Chihuahuan Desert, Texas": presented at the Workshop on Chloride and ^{36}Cl Studies in the Arid Southwest, Las Vegas, Nevada.

"Long-term simulation of nonisothermal liquid and vapor flow in desert soils: case study Chihuahuan Desert, West Texas": presented to the Southwest Research Institute, San Antonio, Texas.

"Results of numerical simulations of nonisothermal liquid and vapor flow in arid systems": presented to the Department of Civil Engineering, Princeton University, Princeton, New Jersey.

"Analysis of unsaturated flow in desert soils": presented to the Department of Geological Sciences Hydrogeology Seminar, The University of Texas at Austin, Austin, Texas.

Daniel D. Schultz-Ela

"Linked extension above/below/within salt sheets," "Asymmetry in reactive diapirs during extension," and "Active diapirism": presented to Applied Geodynamics Laboratory Industrial Associates, Austin, Texas.

Andrew R. Scott

"Composition and origins of coalbed gases": presented to Chevron USA, Inc., and Amoco Production Company, Austin, Texas.

"Calculation of coalbed methane resources": presented to Chevron USA, Inc., and Amoco Production Company, Austin, Texas.

"Geologic controls on the San Juan Basin fairway": presented to the Gas Research Institute Project Advisors Group Meeting, Dallas, Texas.

"Aspects of open-hole cavity completions": presented to the Gas Research Institute, Chicago, Illinois.

Steven J. Seni

"Comparison of salt tectonics in the East Texas Basin and the Gulf of Mexico": presented to the East Texas Geological Society, Tyler, Texas.

Thomas A. Tremblay

"The status of Geographic Information Systems at the Bureau of Economic Geology": presented to the Fourth Biennial GIS Conference, Emphasis on Applications, Austin, Texas.

"Bureau of Economic Geology Border Geographic Information Systems Program": presented to the Lower Rio Grande Development Council, Harlingen, Texas.

Noel Tyler

"Architecture and permeability structure of deltaic reservoirs": presented to ARCO, Plano, Texas.

"Quantifying the architecture of heterogeneous reservoirs": presented to the Society for Industrial and Applied Mathematics Conference, Houston, Texas.

"Landward to seaward variation in heterogeneity style in a distributary-channel and mouth-bar facies tract, Ferron Sandstone, Utah": presented to the Fluvial-Dominated Deltaic Reservoirs in the Southern Midcontinent Workshop, Norman, Oklahoma.

"Increasing production in mature fields": presented to SONATRACH, ARCO, Mobil, and Oryx, Boerne, Texas.

"Oil recovery research": presented to the Desk and Derrick Club, Austin, Texas.

"Base-level dynamics and deltaic reservoir architecture": presented to the Austin Geological Society, Austin, Texas.

"Geophysical resolution of reservoir heterogeneity": presented to Lagoven, S. A., Maracaibo, Venezuela.

Roger Tyler

"Geologic evaluation and fracture characterization of coalbed methane basins, Rocky Mountain foreland, western United States": presented to GENMIN (General Mining), South Africa, at the Bureau of Economic Geology, The University of Texas, Austin, Texas.

"Predicting the distribution of coal deposits in tectonically active foreland basins": presented to Amoco Production Company, Austin, Texas.

"Coal fracture patterns in foreland basins": presented to Amoco Production Company, Austin, Texas.

Bruno C. Vendeville

"Diapirism, thin-skinned extension, salt tectonics: physical modeling (sand-silicone) and natural examples": presented to Elf Aquitaine Research Center, Pau, France.

"Initiation of salt diapirs by thin-skinned and thick-skinned extension": presented to Elf Aquitaine Exploration Company, Paris, France.

"Introduction to salt tectonics and experimental modeling": presented to Georecon A.S., Oslo, Norway.

"The rise and fall of diapirs during thin-skinned extension": presented to Georecon A.S., Oslo, Norway, and to Statoil, Stavanger, Norway.

"Introduction to salt deformation mechanisms and physical aspects of analogue modeling": presented to Statoil, Stavanger, Norway.

"Detached salt tectonics during basement-involved extension": presented to Statoil, Stavanger, Norway.

"Experimental modeling of salt tectonics": presented to the Norwegian Petroleum Directorate, Stavanger, Norway.

"Reactive, active, and passive growth of salt diapirs": presented to the Norwegian Petroleum Directorate, Stavanger, Norway.

"Effect of salt flow and sedimentation on the shape of salt diapirs": presented to Norsk Hydro A.S., Oslo, Norway.

"Genetic association between normal growth faults and salt diapirs": presented to Norsk Hydro A.S., Oslo, Norway.

"Role of basement faults on the formation of salt diapirs": presented to Norsk Hydro A.S., Oslo, Norway.

"Deformation above a transtensional basement graben," "Mechanical effects of progradation on structural style," "Synthetic seismograms from physical models," and "Superposed contraction of extensional diapirs": presented to Applied Geodynamics Laboratory Industrial Associates, Austin, Texas.

"Tectonic inversion of extensional salt diapirs during regional shortening": presented to Norsk Hydro A.S., Oslo, Norway.

"Mechanisms generating normal fault curvature": presented to Norsk Hydro A.S., Oslo, Norway.

Fred P. Wang

"Simulation studies of Seminole San Andres Unit, Gaines County, Texas": presented to ARCO Oil and Gas Company, Midland, Texas.

"Reservoir modeling and simulation on Seminole San Andres Unit, Gaines County, Texas": presented to Amoco Oil and Gas Company, Houston, Texas.

"Reservoir geostatistics, modeling, and simulation": presented as a short course, Quantification of Carbonate Ramp Reservoir Models, The University of Texas at Austin, Bureau of Economic Geology, Austin, Texas.

"Application of outcrop data to simulation study of the Seminole San Andres Unit, Gaines County, Texas": presented to ARCO Oil and Gas Company, Plano, Texas.

"Geostatistics, upscaling, and simulation of carbonate-ramp reservoirs": presented to sponsors at the San Andres–Grayburg Reservoir Characterization Research Laboratory Annual Review Meeting, Carlsbad, New Mexico.

E. G. Wermund

"Texas progress toward developing a data dictionary or a statewide Geographic Information System (GIS) on oil spills": presented to the Minerals Management Service, Gulf of Mexico Regional Office on Outer Continental Shelf Leasing, New Orleans, Louisiana.

"Welcoming address to attendees": presented to the Fourth Biennial GIS Conference, Emphasis on Applications, Austin, Texas.

William A. White

"Status and trends of wetlands and aquatic habitats, Galveston Bay System, Texas": presented at the Second State of the Bay Symposium, Galveston Bay National Estuary Program, Galveston, Texas.

Jiannan Xiang

"Multistep constant head borehole test in the unsaturated zone": presented at the Pantex Project quarterly meeting, Austin, Texas.

"Preferential flow and its effect on the recharge rate": presented at the Pantex Project quarterly meeting, Amarillo, Texas.

"An improved solution for the constant head borehole test": presented to The University of Texas at Austin, Department of Geological Sciences Brown Bag Seminar, Austin, Texas.

Bureau of Economic Geology Seminars

William A. Ambrose

(and Eulise R. Ferrer) "Reservoir characterization of tidally influenced deltaic sandstone reservoirs of the Misoa Formation (lower Eocene), Lagunillas field, Lake Maracaibo, Venezuela"

Mark J. Burn

"Geological, petrophysical, and engineering characterization of undrained thin-bed gas reservoirs from the Frio Formation, North McFaddin field, South Texas"

Sigrid J. Clift

(and H. Scott Hamlin) "Ozona Canyon sandstones: Val Verde Basin"

Bruce K. Darling

"Isotope hydrology of southern Hudspeth County"

Eulise R. Ferrer

(and William A. Ambrose) "Reservoir characterization of tidally influenced deltaic sandstone reservoirs of the Misoa Formation (lower Eocene), Lagunillas field, Lake Maracaibo, Venezuela"

R. Stephen Fisher

"Petrography and permeability relations in the Ferron Sandstone"

Alan E. Fryar

"Geochemical characterization of ground water in the vicinity of the Pantex plant"

H. Scott Hamlin

"Stratigraphy of Canyon sandstones, Val Verde Basin"

(and Sigrid J. Clift) "Ozona Canyon sandstones: Val Verde Basin"

Barry J. Hibbs

"Hydrogeologic study of southern Hudspeth County, Texas—an integrated hydrochemical and numerical modeling approach"

Mark H. Holtz

(and Lee E. McRae) "New oil reserves from old reservoirs in the Frio Fluvial-Deltaic Sandstone play of South Texas"

Susan D. Hovorka

"Late Quaternary playa basin fills on the Southern High Plains, Texas—implications for Ogallala recharge and playa basin evolution"

Martin P. A. Jackson

"Retrospective and prospective salt tectonics"

Mary L. W. Jackson

"Earth fissures and fissurettes on Faskin Ranch, far West Texas"

Eric W. James

"Linking biostratigraphy and chemostratigraphy—high-precision strontium isotope stratigraphy using single conodont elements"

Paul R. Knox

"Reservoir characterization of West Fulton Beach field"

Richard P. Langford
"Surficial deposits and processes and geomorphology of the Eagle Flat Basin"

Robert E. Mace
"Use of hand-dug wells in hydrogeologic investigations"

Richard P. Major
"Reservoir characterization of Keystone field, West Texas"

Amanda R. Masterson (and Publications staff)
"Producing your publications: from inspiration to distribution"

Lee E. McRae
(and Mark H. Holtz) "New oil reserves from old reservoirs in the Frio Fluvial-Deltaic Sandstone play of South Texas"

William F. Mullican III
"Hydrogeologic characterization of perched aquifers and their potential impact on contaminant transport at the U.S. Department of Energy Pantex plant, Southern High Plains, Texas"
"The Bureau's drilling program—capabilities, accomplishments, and future"

H. Seay Nance
"Stratigraphy and depositional setting of Cretaceous siliciclastics—western margin of the East Texas Basin"

Jeffrey G. Paine
"To bedrock and beyond: rationale, methods, and results of shallow seismic studies at the Bureau of Economic Geology"

Douglas B. Swift
"A productive lower Atoka chenier–barrier bar trend in the Permian Basin: its stratigraphic and structural implications"

Roger Tyler
"Syntectonic sedimentation in the Paleocene Fort Union Formation, Sand Wash Basin, northwestern Colorado and southwestern Wyoming"

Bruno C. Vendeville
"Growth rates of salt structures in nature and experiments"

E. G. Wermund
"A lineation analysis of the Eagle Flat area, Hudspeth County, Texas, related to siting a Texas low-level radioactive waste repository"

William A. White
"Loss of wetlands in the Galveston Bay system"

Jiannan Xiang
"Constant head borehole test on the unsaturated zone"
"Applications of optimization—parameter estimations and decision making"

Congressional, Legislative, and Special Testimony

William L. Fisher
"Statement on current state of the oil and gas industry": presented to the U.S. Senate Committee on Energy and Natural Resources, J. Bennett Johnson, Chairman, Houston, Texas.
"Statement on HB 1221, Texas Geologists and Geophysicists Registration Act": presented to the State Affairs Committee, Texas House of Representatives, Austin, Texas.

Auburn L. Mitchell
"Testimony on Senate Bill 459: adding the Bureau of Economic Geology to the Texas Groundwater Protection Committee": presented before the State of Texas House Committee on Natural Resources, Austin, Texas.

Committee Services, Offices, and Other Professional Responsibilities

Don G. Bebout
Member, Preservation of Cores and Samples Committee, American Association of Petroleum Geologists.

Sigrid J. Clift
Leader of field trip, "Field trip through the Llano Uplift," Lago Vista Middle School eighth grade science classes, Llano area, Texas.

Edward W. Collins
Chairman, Poster Sessions, Gulf Coast Association of Geological Societies 1994 Annual Meeting.
Member, Officer-Election Committee, Austin Geological Society.

Alan R. Dutton
Editor, *The Hydrogeologist*.

Shirley P. Dutton
Associate Editor, *Journal of Sedimentary Petrology*, SEPM (Society for Sedimentary Geology).
General Program Chairman, Gulf Coast Association of Geological Societies 1994 Annual Meeting.
Member, Steering Committee, Gulf Coast Association of Geological Societies 1994 Annual Meeting.
Member, Grants-in-Aid Committee, American Association of Petroleum Geologists.
Member, Joint Technical Program Committee, Geological Society of America, representing the Sedimentary Geology Division.

Robert J. Finley

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

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

Member, Working Group, Texas Committee on Energy Policy and Texas Energy Coordination Council.

R. Stephen Fisher

Member, Ad Hoc Committee on Hydrogeology and Environmental Geology, SEPM (Society for Sedimentary Geology).

Co-convenor, "Hydrology: stratigraphic controls on ground-water flow and processes" special session, American Geophysical Union Fall Meeting.

William L. Fisher

President, American Institute of Professional Geologists.

Vice President, Gulf Coast Association of Geological Societies.

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

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

Chairman, Outlook Committee, State of Texas Energy Policy Partnership.

Chairman, Board on Earth Sciences and Resources, National Academy of Sciences/National Research Council.

Chairman, Energy Policy Committee, Association of American State Geologists.

Chairman, Applied Research and Technology Committee, Texas Independent Producers and Royalty Owners (TIPRO).

Board of Advisors, Jefferson Energy Foundation Project on Man, Energy, and the Environment.

Foundation Trustee, American Geological Institute.

Ex Officio Member, U.S. National Committee on Geology, National Academy of Sciences/National Research Council.

Ex Officio Member, U.S. National Committee for the International Geophysical Union, National Academy of Sciences/National Research Council.

Ex Officio Member, U.S. National Committee for the International Union of Geology and Geophysics, National Academy of Sciences/National Research Council.

Ex Officio Member, U.S. National Committee for the International Union for Quaternary Research, National Academy of Sciences/National Research Council.

Ex Officio Member, Potential Resources Committee, Independent Petroleum Producers of America.

Charter Member, Secretary of Energy Advisory Board (SEAB), U.S. Department of Energy.

Member, Advisory Council, Bureau of Business Research, The University of Texas at Austin.

Member, Committee on Governmental Relations, Natural Sciences Foundation, The University of Texas at Austin.

Member, Economic Analysis and Modeling Task Force, U.S. Department of Energy.

Member, Research Committee, Interstate Mining Compact Commission.

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

Member, Texas Ground-Water Protection Committee.

Member, Advisory Council, Gas Research Institute.

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

Trustee, Southwest Research Institute.

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

Member, Advisory Board, World Energy Update.

Member, Advisory Board, Treatise on Petroleum Geology, American Association of Petroleum Geologists.

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

Member, Industry Liaison Committee, American Association of Petroleum Geologists.

Member, Executive Committee, Committee on Status and Research Objectives in the Solid Earth Sciences, National Academy of Sciences/National Research Council.

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

Member, Endowment Fund Steering Committee, Association of American State Geologists.

Member, Steering Committee, National Geoscience Data Repository System.

Member, Nominating Committee, Advisory Council, Gas Research Institute.

Member, National Petroleum Council.

Member, Executive Committee, Texas Independent Producers and Royalty Owners (TIPRO).

Member, Petroleum Technology Transfer Council.

Trustee Associate, American Association of Petroleum Geologists Foundation.

William E. Galloway

Member, Pettijohn Medal Award Committee, SEPM (Society for Sedimentary Geology).

L. Edwin Garner

Member, Crisis Committee, Gulf Coast Association of Geological Societies 1994 Annual Meeting.

Member, Steering Committee, Gulf Coast Association of Geological Societies 1994 Annual Meeting.

Member, Membership Committee, American Association of Petroleum Geologists.

Co-leader of field trip, "Geology of state parks," Austin Geological Society Spring Field Trip, Central Texas.

Chester M. Garrett, Jr.

Chairman, Austin Delegation, American Association of Petroleum Geologists House of Delegates.

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

Member, Grants-in-Aid Committee, American Association of Petroleum Geologists.

Member, Registration Committee, Gulf Coast Association of Geological Societies 1994 Annual Meeting.

Member, Exhibits Committee, Gulf Coast Association of Geological Societies 1994 Annual Meeting.

Judge, Matsen Award, American Association of Petroleum Geologists 1993 Annual Meeting.

Douglas S. Hamilton

Chairman, Membership Committee, Austin Geological Society.

Bob A. Hardage

Member, Executive Committee, Society of Exploration Geophysicists.

Editor, Society of Exploration Geophysicists, *Geophysics*.

Assistant Editor, Society of Exploration Geophysicists, *Geophysics*.

Chairman, DOE/BES Geoscience Research Review Panel.

Member, Publications Committee, Society of Exploration Geophysicists.

Member, Organizing Committee, Society of Exploration Geophysicists Research Forum.

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

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

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

Member, Visiting Committee, Department of Petroleum Engineering, The University of Texas at Austin.

Member, Geophysical Committee, American Association of Petroleum Geologists.

Co-chairman, Borehole Geophysics Session, 1993 Annual Archie Conference, Houston, Texas.

Mark H. Holtz

Chairman, Registration Committee, Gulf Coast Association of Geological Societies 1994 Annual Meeting.

Technical editor, Society of Petroleum Engineers, *Reservoir Engineering*.

Martin P. A. Jackson

Associate Editor, Geological Society of America *Bulletin*.

Co-convenor and session co-chairman, International Hedberg Research Conference on Salt Tectonics, Bath, United Kingdom, organized and sponsored by the American Association of Petroleum Geologists.

Member, International Union of Geological Sciences Commission on Tectonics.

Mary L. W. Jackson

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

William R. Kaiser

Co-leader of field trip, "Lignite resources of northeast Texas," Gulf Coast Association of Geological Societies Annual Meeting, northeast Texas.

Member, Steering Committee on Coal Reserves Assessment, U.S. Department of Energy.

Charles Kerans

Leader of field trip, "Geology of the Leonardian–Guadalupian strata of the Guadalupe Mountains," Phillips Petroleum Company, Carlsbad, New Mexico.

Leader of field trip, "Paleozoic stratigraphy of the Llano Uplift," Oryx, ARCO, Mobil, and SONATRACH Oil Companies, Llano area, Texas.

Leader of field trip, "Devonian reef complexes and sequence stratigraphy of the Lennard Shelf, Canning Basin, western Australia," Fitzroy Crossing, Australia.

Co-leader of field trip, "Sequence framework of the Albian carbonates of southwest Texas as a basis for reservoir analog research," TOTAL and KSEPL, Del Rio area, Texas.

Leader of field trip, "Edwards Platform to Maverick Basin transect, sequence perspective on an Albian intrashelf basin," Carbonate Reservoir Characterization Research Laboratory sponsors, Queen area, New Mexico.

Stephen E. Laubach

Convenor, "The geology of natural gas resources: challenges and opportunities," theme session, Geological Society of America 1993 Annual Meeting, Boston, Massachusetts.

Co-convenor, "Naturally fractured reservoir evaluations," technical session, 1993 Joint Society of Petroleum Engineers Rocky Mountain Regional and Low-Permeability Reservoir Symposium, Denver, Colorado.

Co-chairman, First North American Rock Mechanics Symposium (1994 meeting).

Member, Local Organizing and Program Committee, First North American Rock Mechanics Symposium (1994 meeting).

Member, Technical Program Committee, 1993 Joint Society of Petroleum Engineers Rocky Mountain Regional and Low-Permeability Reservoir Symposium.

Member, Committee on Advanced Drilling Technology, Geotechnical Board, National Research Council.

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Chairman, Audio Visual and Speakers Assistance Committee, Gulf Coast Association of Geological Societies 1994 Annual Meeting.

Alternate, Working Group, Texas Committee on Energy Policy and Texas Energy Coordination.

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Associate Editor, Society of Petroleum Engineers, *Journal of Petroleum Technology*.

Co-convenor of poster session, "Dolomitization and porosity evolution," Annual Meeting of the American Association of Petroleum Geologists.

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

Associate Editor, Book Reviews, *Journal of Sedimentary Petrology*.

Delegate, House of Delegates, American Association of Petroleum Geologists, representing the Austin Geological Society.

Editor, Gulf Coast Association of Geological Societies, *Transactions*, 1994 Annual Meeting.

Member, Steering Committee, Gulf Coast Association of Geological Societies 1994 Annual Meeting.

Co-convenor of poster session, "Dolomitization and porosity evolution," Annual Meeting of the American Association of Petroleum Geologists.

Session chairman, "Sedimentology, carbonate II: diagenesis," Annual Meeting of the Geological Society of America.

Judge, SEPM poster session, "Carbonate diagenesis," Annual Meeting of the American Association of Petroleum Geologists.

Judge, SEPM oral session, "Carbonate diagenesis," Annual Meeting of the American Association of Petroleum Geologists.

Lee E. McRae

Judge, SEPM/AAPG (Society for Sedimentary Geology) poster session, "Sequence stratigraphy–sedimentary basin architecture," American Association of Petroleum Geologists 1993 Annual Meeting.

Judge, SEPM Research Symposium (Society for Sedimentary Geology) oral session, "Geochronology, time-scales, and correlation," American Association of Petroleum Geologists 1993 Annual Meeting.

Member, Program Committee, Gulf Coast Association of Geological Societies 1994 Annual Meeting.

Member, Registration Committee, Gulf Coast Association of Geological Societies 1994 Annual Meeting.

Chairman, Membership Committee, Austin Geological Society.

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Member, Editorial Board, *Journal of Coastal Research.*

Associate Editor, *Journal of Sedimentary Petrology.*

Member, Meetings Policy Committee, SEPM (Society for Sedimentary Geology).

Member, Nominating Committee, SEPM (Society for Sedimentary Geology).

William F. Mullican III

Member, Texas Water Management Coordination Committee.

Member, Texas Ground-Water Protection Committee, Data Management Subcommittee.

Jay A. Raney

Texas representative, U.S. Department of Energy State and Tribal Government Working Group, Washington, D.C.

Texas representative, AIP Forum on Environmental Programs, Boise, Idaho.

Member, GIS Planning Council, Texas Department of Information Resources.

Stephen C. Ruppel

Chairman, Publications Committee, Austin Geological Society.

Co-convenor of poster session, "Dolomitization and porosity evolution," Annual Meeting of the American Association of Petroleum Geologists.

Andrew R. Scott

Regional Committee Representative, Energy Minerals Division, Gulf Coast Association of Geological Societies.

Steven J. Seni

Chairman, Field Trip Committee, Austin Geological Society.

Chairman, Sports Committee, Gulf Coast Association of Geological Societies 1994 Annual Meeting.

Thomas A. Tremblay

Representative, Geographic Information Systems Managers Committee, Austin, Texas.

Noel Tyler

Chairman, Illinois Geological Society 1992 Symposium, Advances in Reservoir Characterization for Improved Oil Recovery, Champaign, Illinois.

Convenor, Oil Reserve Growth Technology Transfer School, Texas Independent Producers and Royalty Owners Association, Austin, Texas.

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

Member, External Advisory Committee, Center for Research on Parallel Computation, Rice University, Houston, Texas.

Roger Tyler

Member, Committee for Session Development, First North American Rock Mechanics Symposium (1994 Annual Meeting).

Co-convenor, Gas Research Institute/Bureau of Economic Geology Natural Fracture Workshop.

Judge, SEPM (Society for Sedimentary Geology) Best Poster Award, American Association of Petroleum Geologists 1993 Annual Meeting.

Judge, Energy Minerals Division Best Paper Award, American Association of Petroleum Geologists 1993 Annual Meeting.

Bruno C. Vendeville

Member, Editorial Board, *Tectonophysics.*

Member, Committee for Session Development, First North American Rock Mechanics Symposium (1994 Annual Meeting).

E. G. Wermund

Co-chairman and Representative for Texas, Gulf of Mexico Regional Technical Working Group, Minerals Management Service, U.S. Department of the Interior.

Vice-chairman, Texas Natural Resources Information System Task Force.

Member, Texas Mapping Advisory Committee.

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

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

Member, Membership Committee, Geological Society of America.

William A. White

Alternate, Remote Sensing and Cartographic Committee, Texas Natural Resources Information System Task Force.

University Teaching/ Continuing Education

William A. Ambrose

"Strategies for reserve growth in LL-652 area, Lagunillas field, Venezuela": co-lecturer of workshop presented to Lagoven, S. A., Maracaibo, Venezuela.

Don G. Bebout

"Carbonate field seminar—Lower Cretaceous platform carbonates, Central Texas—surface to subsurface": co-lecturer of short course presented to the American Association of Petroleum Geologists, Field Seminar Series, San Antonio and Austin, Texas.

"Description and interpretation of carbonate cores": short course presented to The University of Texas at Austin, Department of Geological Sciences (Geology 383N), Austin, Texas.

William E. Galloway

"Depositional systems and sequences in exploration for sandstone reservoirs": short course presented to The University of Adelaide, National Centre for Petroleum Geology and Geophysics, Adelaide, Australia.

H. Scott Hamlin

"Strategies for reserve growth in Tirrawarra field": co-lecturer of short course and core workshop presented to Santos Ltd., Adelaide, Australia.

Bob A. Hardage

"Reservoir geophysics": short course presented to the Geophysical Society of Houston, Houston, Texas, and to the Society of Exploration Geophysicists, Washington, D.C.

"3-D seismic technology": short course presented to the Texas Independent Oil and Gas Associations, Dallas, Amarillo, Abilene, Midland, and Wichita Falls, Texas.

"Onshore 3-D seismic technology for increased gas recovery": co-lecturer of public short course presented in Houston, Texas, in cooperation with the Geophysical Society of Houston and the Houston Geological Society.

Martin P. A. Jackson

"Advanced salt tectonics": short course presented to Oryx Energy Company, Dallas, Texas.

William R. Kaiser

"Coal as source rock and gas reservoir": co-lecturer of short course presented to the 1993 International Coalbed Methane Symposium, Birmingham, Alabama.

Raymond A. Levey

"Onshore 3-D seismic technology for increased gas recovery": co-lecturer of public short course presented in Houston, Texas, in cooperation with the Houston Geological Society and the Geophysical Society of Houston.

Robert E. Mace

"Recent progress in determining fracture aperture in geologic materials": The University of Texas at Austin, Department of Geological Sciences (Geology 391C), Austin, Texas.

Noel Tyler

"Architectural controls on oil recovery—resources and implications for reserve growth": presented to the Texas Independent Producers and Royalty Owners Association Technology Transfer School, Abilene, Midland, Houston, and Wichita Falls, Texas.

"Strategies for reserve growth in LL-652 area, Lagunillas field, Venezuela": co-lecturer of workshop presented to Lagoven, S. A., Maracaibo, Venezuela.

"Strategies for reserve growth in Tirrawarra field": co-lecturer of short course and core workshop presented to Santos Ltd., Adelaide, Australia.

"Geophysical resolution of reservoir heterogeneities": presented at Merton College, Oxford University, Oxford, England.

Support Staff

Administrative/Secretarial

The Administrative staff, under the supervision of Wanda LaPlante, Executive Assistant, handle the general administration of the Bureau, which includes personnel, accounts payable and receivable, publication sales, purchasing, travel, reception/switchboard, and correspondence. Ninety percent of all documents handled by this section are processed electronically. The Bureau's involvement in numerous contracts and research projects requires that the Administrative staff process more than 3,500 appointment forms each year in order to allocate staff time among funding sources properly. This section also controls more than $5 million in purchases and subcontracts and handles publication sales in excess of $150,000 per year.

Ginger Zeikus Mourned

Virginia C. (Ginger) Zeikus died February 20, 1993, in Austin. Mrs. Zeikus had worked for the Bureau since September 1978 and was on leave at the time of her death. She joined the Bureau when the West Texas Waste Isolation project was a major part of Bureau research. Her first assignment was as Senior Secretary to L. F. Brown, Jr., then Associate Director of the Bureau. Dr. Brown recalls Zeikus as

> *always more than a highly qualified secretary and the only onsite administrative support at the Bureau's satellite facility at 16th and Lavaca, fondly called 'Bureau South.' Ginger personally and cheerfully attended to every staff member's and graduate assistant's requests for help. She was, perhaps, a bit shy, quiet spoken, patient, and always polite and courteous to everyone. Yet Ginger possessed a strong will and a highly professional attitude about her responsibilities. Those of us who worked closely with Ginger Zeikus will probably remember and appreciate her most for her wonderful human qualities. She was a loyal friend and a very special lady.*

Zeikus later worked for Marcus E. Milling, Associate Director, and then as an Administrative Associate on the Administrative staff. She helped with word processing and various administrative duties and was a dedicated and productive member of the support staff. Her contributions were valued by her peers and supervisors, and she will be missed and fondly remembered by her friends at the Bureau.

Cartography

The Cartographic section, although well known for producing high-quality products, is best known for producing full-color maps in support of Bureau contracts.

The section's 14-person full-time staff, directed by Richard L. Dillon, Chief Cartographer, produced 2 black-and-white plates, 10 full-color maps, 2,150 text figures, and 1,825 visual aids in 1993. All items produced by this staff are published in Bureau publications, contract reports, or articles in professional journals, or they are used in presentations at local and national meetings. Because these materials are used publicly, high cartographic standards must be maintained.

In 1993 the Cartographic section had come to rely on computers more and more to complete its work. Currently 75 to 80 percent of all text figures and visual aids are produced on eight Macintosh computers. Cartography also has a black-and-white laser printer, a 300-dpi color printer, a dye sublimation color printer, a black-and-white scanner, and a color scanner—all of which support the Macintosh computers. Cartographers can draft at a UNIX-based DEC workstation and digitizing table using ARC/INFO software to make maps on the Bureau's Geographic Information System.

In Memoriam: Bureau Remembers James W. Macon

James W. Macon, Chief Cartographer of the Bureau from 1950 to 1981, died October 1, 1993. Mr. Macon began working part time at the Bureau on May 6, 1948, while still a student at the University of Texas. Bureau cartographer Barbara M. Hartmann, who worked for Macon for more than 20 years, recalls that Macon "guided the drafting division with great ingenuity and invention" to make it "one of the most highly regarded cartographic laboratories in the country." She noted that, along with his well-organized and equally inventive colleagues, Macon saw Cartography through lean times when getting the essential equipment to keep in step with the changing technology of mapmaking was difficult. In the early years, before the Bureau could afford sophisticated equipment, color proofs were made by exposing them to sunlight. Macon's career spanned innovations in cartographic techniques from early drawing in pen and ink to scribing in the 1950's to using photogrammetry in the late 1950's and early 1960's. Major projects completed during Macon's career at the Bureau include the four-quadrant Land Resources of Texas map and the Environmental Geologic Atlas of the Texas Coastal Zone. All but 4 of the 38 map sheets composing the Geologic Atlas of Texas were published during Macon's tenure. Macon retired in August 1981 after 33 years of service to the Bureau. During his retirement he enjoyed traveling and spending time with his family.

Computer Resources

Computer Resources supports programming, data-base applications, statistical and graphic data analysis, and computer mapping and modeling on the Bureau's computer system and on the University's IBM, VAX, CONVEX, and Cray computer systems.

The Bureau's computer system features a Local Area VAX Cluster (LAVC) that has a VAX 4000 as a boot node. Three VAXstation 3100's and a MicroVAX II serve as satellite nodes in this LAVC. Computer Resources also maintains two DECstation 5000's, an IBM RS6000, a Silicon Graphics, Inc. (SGI), Elan workstation, and two SGI Indigo workstations. All workstations can be accessed through the Bureau's Xyplex terminal server, and a print server provides network access to two line printers. An Ethernet network connects all workstations in-house.

The Bureau also has 95 Macintoshes, 30 IBM-compatible PC's, 15 Apple LaserWriters, and 108 VAX terminals. All Macintoshes are networked into a LocalTalk network that connects to the Bureau's Ethernet. The Bureau's local networks are connected to the University's broad-band Ethernet system, which allows high-speed communication with computer systems on campus, at the Center for High Performance Computing, and at other Internet sites worldwide.

Computer Resources installs and maintains software tools such as data-base, word-processing, spreadsheet, and statistical packages, all of which are implemented on VAXcluster, Macintosh, and PC platforms. Seismic data display, interpretation, and modeling can be accomplished on both workstations and Macintoshes. Water-flow modeling, reservoir modeling, and well log interpretation packages are also supported on Bureau workstations.

Geographic Information System (GIS) resources consist of ARC/INFO and ArcView software on a DECstation 5000 workstation. Two IBM-compatible PC's and an X-terminal serve as additional "seats" on the system. Several Calcomp digitizing tablets provide input of map data. Hard-copy maps can be generated using Hewlett Packard DraftPro and 7475 plotters, as well as both a 36-inch color and a 22-inch black-and-white Versatec electrostatic plotter.

Publications

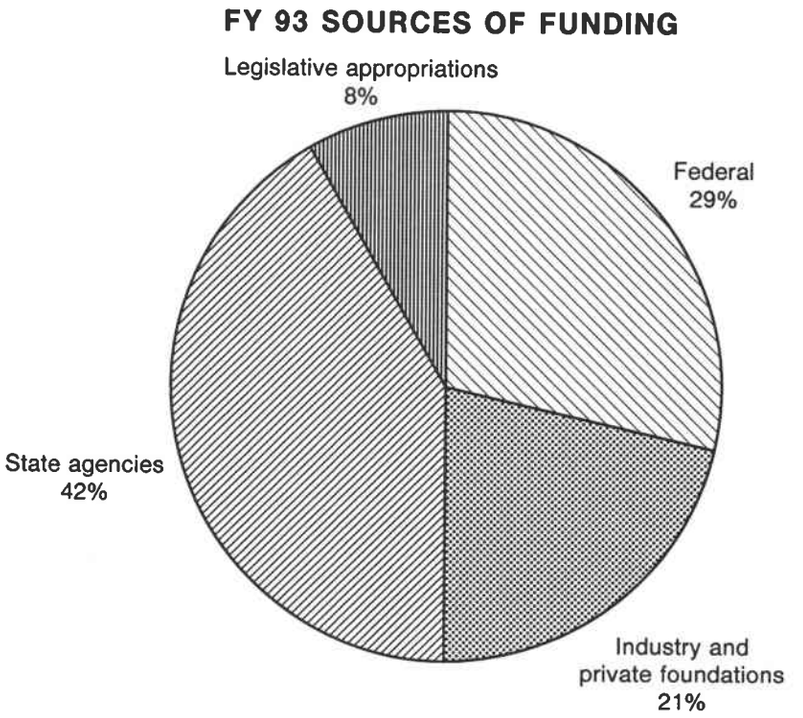
The Publications staff (supervised by Amanda Masterson), consisting of designers, editors, proofreaders, and a word processor/typesetter operator, produces a variety of printed materials for the Bureau. In addition to Bureau publications, the staff also prepares contract reports, papers and abstracts, and various documents in support of research projects. Bureau reports are now produced using desktop publishing technology, by which manuscripts are revised electronically and pages are prepared for the printer using layout programs. This year, for the first time, a four-color guidebook was electronically created in-house. Nine new publications were issued by the Bureau in 1993. Fifty-three contract reports were also completed, and 210 papers and abstracts by Bureau authors were published by professional journals and publishers.

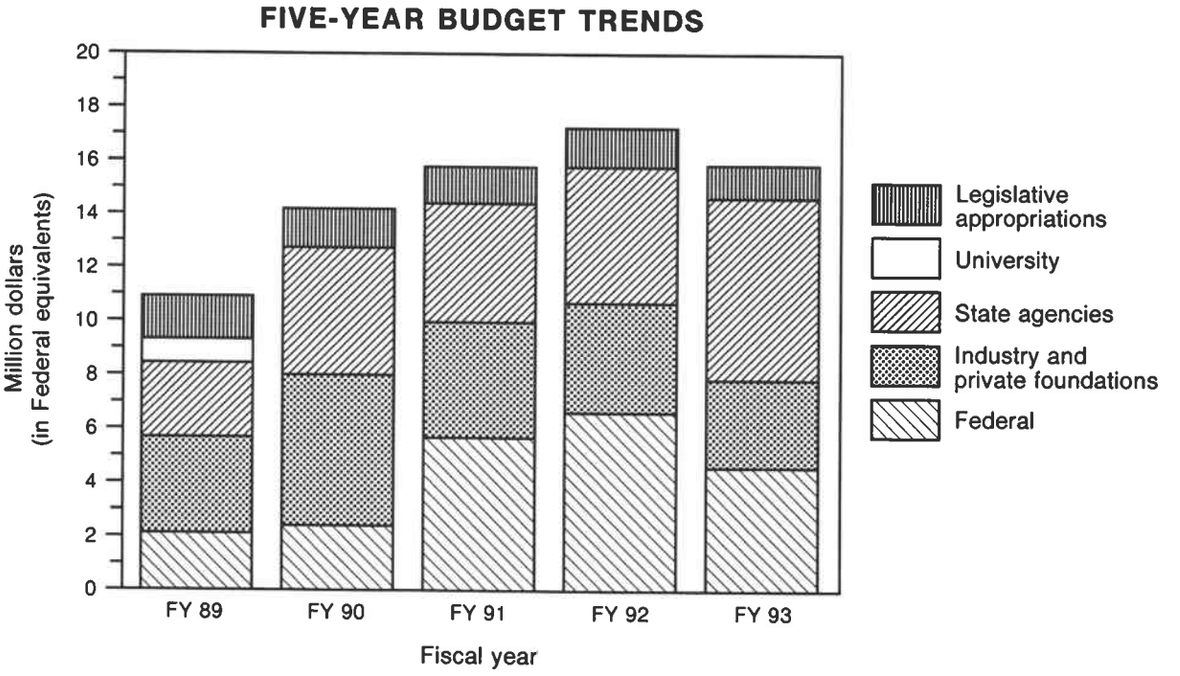
Quality Assurance

The Bureau of Economic Geology has maintained a formal quality assurance program since 1979. The program is documented in written instructions that address research activities, analytical procedures, and methods for verifying and documenting the achievement of quality. The Bureau's quality assurance program conforms to requirements and standards contained in the Texas Constitution, Article XVI, Section 59(a); 10 CFR Part 50, Appendix B; 10 CFR Part 61; ANSI/ASME NQA-1; NUREG-0856; NUREG-1199; NUREG-1293; and NUREG-1383. The program also meets requirements promulgated by the U.S. Department of Energy and U.S. Environmental Protection Agency.

During 1993, quality assurance personnel participated in four Bureau research projects: Geologic Studies of West Texas Bedded Salt Deposits; Geologic and Hydrologic Studies of the Eagle Flat Area–Phase II; Comprehensive Hydrogeologic Investigations of Regional Ground-Water Flow and Ground-Water Resources, Ellis County Area, North Texas; and Geologic and Hydrologic Characterization of the Pantex Plant. The Bureau's quality assurance manager also assisted the Texas Low-Level Radioactive Waste Disposal Authority in developing and implementing their quality assurance program.

Sources of Funding and Budget Trends





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