Annual Report

1988

Bureau of Economic Geology
W. L. Fisher, Director
The University of Texas at Austin
Austin, Texas 78713

Foreword

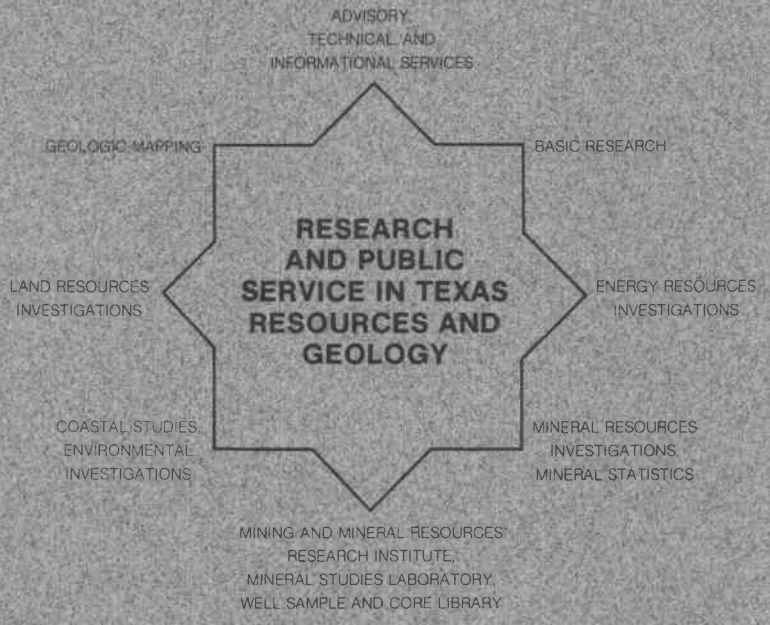
The Bureau of Economic Geology, established in 1909 as the successor to the Texas Geological Survey and the Texas Mineral Survey, is a research entity of The University of Texas at Austin. It also functions as the State Geological Survey, a quasi-State agency, and the Bureau Director represents Texas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

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

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

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

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



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Contents

Research

Publications

Services

Highlights of the Year

Research Staff Publications and Activities

Support Staff

Research

Reflecting the Bureau of Economic Geology's dual function as a research entity of The University of Texas at Austin and as the State geological survey, research in 1988 involved both investigations of Texas' energy, land, and water resources and environmental and waste-disposal concerns, and a variety of basic-research projects, such as geologic mapping and regional structural and stratigraphic studies. In addition to the continuation of several multiyear projects, significant new programs were initiated during the year. Prominent among these are (1) the Geoscience Institute for Oil and Gas Recovery Research, composed of a national consortium of 21 universities and other state surveys and headquartered at the Bureau, (2) the Secondary Gas Recovery program, a 3-year $22 million study to develop technologies for improved efficiency of natural gas production, and (3) the Applied Geodynamics Laboratory, a joint university/industry-funded facility designed for the modeling of tectonic and structural geologic processes at various scales. In addition, Bureau geoscientists submitted proposals to the highly competitive Texas Higher Education Coordinating Board's Advanced Technology and Advanced Research Programs and received funding for five diverse research topics, including salt tectonics of the northern Gulf of Mexico and gas-saturation effects on geopressured sediments along the Texas Gulf Coast. The year also brought the phaseout of the Bureau's long-standing Geologic Studies of West Texas Bedded Salt Deposits project, which was initially funded by the U.S. Department of Energy in 1977 to evaluate the proposed site of a high-level radioactive waste repository in Deaf Smith County.

Assessment, quantification, and geologic analysis of the state's vast petroleum and natural gas resources were the focus of new and ongoing research programs conducted during 1988. Primary emphasis was placed on investigation of methods to increase production from older, mature hydrocarbon reservoirs. For more than 4 years the Bureau has conducted an integrated geologic/engineering study sponsored by The University of Texas System of remaining mobile oil in selected San Andres/Grayburg reservoirs on University Lands located in the Permian Basin. Analysis of subregional facies geometry, depositional environments, rock fabric/petrophysical properties, and production trends has helped to identify the geologic heterogeneity patterns in these carbonate reservoirs. A three-dimensional computer model of permeability applied to a section of the Dune field on University Lands enabled stochastic simulation of fluid flow and, thus, visualization of the complexity of the reservoir architecture. The continuing objective of these efforts has been to provide operators the information necessary to attain more effective oil recovery from infill-drilling operations. In other related projects, state-wide and play-specific surveys of recoverable mobile oil have enabled more accurate quantification of the state's resource base. Of particular interest has been the pronounced effects of interwell lithologic (facies) and diagenetic heterogeneity on recovery potential of large plays in the Midland Basin, Central Basin Platform, and Gulf Coast Basin. An ambitious new program was initiated to model such interwell heterogeneity of San Andres/Grayburg reservoirs through detailed outcrop and core studies, integrated with regional subsurface analysis, of the exceptional 17-mi-long, dip-oriented carbonate-ramp exposures of the Algerita escarpment in the Guadalupe Mountains of New Mexico. In addition to reexploration of mature onshore regions, the Bureau is also involved in research of deep-water exploration areas. Industry's interest in targets on the northwest Gulf of Mexico continental shelf and slope is evidenced by its continuing support of a Bureau program to determine the petroleum potential in this region.

Sophisticated efforts are required to quantify and devise strategies to improve production from low-permeability (tight) gas reservoirs, hydropressured gas reservoirs, and other unconventional gas sources both in Texas and in the nation. These reservoirs are typically difficult to produce from, and a better understanding of factors controlling porosity and permeability, fracture distribution, and state of stress in the reservoirs is needed to help improve completion techniques and increase recoveries. A 6-year program sponsored by the Gas Research Institute investigating gas sandstone reservoirs of the Travis Peak Formation of East Texas was expanded this year to include characterization of the underlying Cotton Valley Group and low-permeability sandstones in North Texas, New Mexico, Colorado, and Wyoming. Bureau researchers are also examining unconventional gas resources in coal-bearing strata of the Fruitland Formation in the San Juan Basin, Colorado and New Mexico, to determine the various geologic and hydrologic controls on coalbed methane occurrence and producibility. This study is part of a larger, multiagency project funded by the Gas Research Institute

to evaluate coalbed methane resources in the San Juan and Black Warrior Basins, the major methane-producing basins in the United States.

"An Assessment of the Natural Gas Resource Base of the United States" was completed by the Bureau for the U.S. Department of Energy during 1988. Included in the assessment were seven categories of lower 48 states' conventional natural gas resources, ranging from proved reserves to undiscovered resources, in addition to unconventional gas resources and gas resources in Alaska. The assessment was conducted starting with an understanding of major components of the natural gas supply based on existing resource estimates derived using established methodologies. In addition to historically defined elements of the natural gas resource base, a new component—reserve growth in heterogeneous reservoirs—was estimated at 119 trillion cubic feet (Tcf) by the Bureau. Critically, this assessment was based on technically and economically recoverable natural gas volumes judged to be conservative by a national Review Panel of 17 leading geologists, engineers, and economic analysts from government, industry, and the non-profit private sector. Results indicated a resource base of 1,059 Tcf in the lower 48 states, of which more than half, or 583 Tcf (nearly a 35-year supply), was recoverable at a 1987 wellhead price of less than $3.00/thousand cubic feet (Mcf).

The "Atlas of Major Texas Gas Reservoirs," the companion volume of the Bureau's popular 1983 "Atlas of Major Texas Oil Reservoirs," is scheduled for publication in cooperation with the Gas Research Institute in late 1989. The atlas groups approximately 2,000 reservoirs that have each produced more than 10 billion cubic feet (Bcf) of gas into 73 geologically distinct plays, based on age, lithology, formation, reservoir genesis, trapping mechanism, petrophysical properties, and geographic location. The atlas will serve as a basis for future studies of gas-reserve growth in specific fields and plays and will initiate detailed field and subregional geologic analyses of gas-reservoir heterogeneity.

In 1988 the Texas Low-Level Radioactive Waste Disposal Authority continued its sponsorship of the Bureau's detailed geologic and hydrologic investigation of a potential waste-repository site in Hudspeth County, West Texas. The host sediments of the repository compose a thick terrigenous clastic sequence of upper Cenozoic basin-fill deposits of the Hueco Bolson near Fort Hancock. Evaluation of the mandated long-term (300- to 500-yr) integrity of the proposed site is the main objective of this project. Stratigraphic studies of the bolson have detailed the variation in the waste-containment properties of the sediments and have aided in the engineering analysis and design of the potential repository. Bureau hydrologists assessed the permeability and groundwater dynamics of the host sediments, and structural and geomorphic specialists considered the local and regional seismic risk and surface-erosion potential, respectively. Data, interpretations, and recommendations will be reported to the Authority in August 1989.

Bureau projects addressed a range of environmental issues of interest to Texas and the United States. The U.S. Environmental Protection Agency (EPA) is funding a study to develop the methodology for delineating wellhead protection areas for wells in confined aquifers as part of a nationwide program to prevent contamination of the country's water supply. The result will be a technical manual providing guidelines for state water agencies to define wellhead protection areas in their states. In other EPA-funded projects, Bureau hydrologists and geochemists completed (1) an investigation of the fluid-migration potential of saline strata used for deep-well injection of chemical wastes and (2) an analysis of the deep-subsurface degradation of hazardous wastes disposed of by deep-well injection. Because organic contamination of ground water is a common problem at many U.S. Air Force bases, the U.S. Air Force Training Command contracted the Bureau to inspect geologic and hydrologic controls on the distribution of organic ground-water contaminants beneath Reese Air Force Base in Lubbock, Texas. The Lower Colorado River Authority funded a program at the Bureau to study surface- and ground-water management strategies in Wharton and Matagorda Counties, a region of the Texas Gulf Coast undergoing population and industrial growth. Stratigraphic and hydrochemical data aided in the construction of computer models of the local ground-water flow system in these areas.

Bureau mineral resource investigations focused on a variety of commodities throughout the state. In 1988 Bureau researchers continued petrogenetic and geochemical studies of recently discovered high-grade beryllium deposits associated with laccolithic rhyolite intrusions near Sierra Blanca in West Texas. Besides being classified as a strategic metal, beryllium has important applications in the electronics and nuclear-power industries, and because of its low atomic weight but relative high strength, it is of potential use in construction of aviation and space-exploration hardware. The Sierra Blanca deposits are also low-grade sources of other strategic and critical elements, including several rare earth elements. The Bureau also conducted an evaluation of the sizes, distribution, and ages of epithermal gold-silver veins in Trans-Pecos Texas and northern Mexico

to determine their genetic relation to periods of regional Tertiary tectonism. Monitoring and inventorying of Texas' cement and dimension-stone (limestone, granite) production, as well as of non-fuel resources (sand, gravel, heavy minerals) of the Texas Outer Continental Shelf, continued during the year.

In keeping with the Bureau's history of comprehensive study of Texas Gulf Coast geology and biology, researchers continued investigations of coastal sedimentary dynamics, geochemistry, and biota. The long-term State Submerged Lands of Texas project, an extensive inventory of State coastal submerged lands and associated wetlands that covers the entire Texas coast, neared completion in 1988. The last two of the seven atlases are in the final stages of publication and will be available in late 1989. In a new project for the Texas Parks and Wildlife Department the Bureau studied the present and historical role of fluvial sediments in developing and maintaining habitats in estuarine and marine areas along the Texas coast. Field investigations centered on the Colorado and Trinity River delta areas and involved determination of river-sediment and marsh-aggradation rates, sediment composition, vegetation characteristics, and their myriad interrelations. Along other portions of the coast, both short- and long-term shoreline and vegetation-line changes due to natural processes (for example, hurricanes) and residential/industrial development were monitored during the year.

Revision and updating of geologic maps, especially those of a state as large and geologically diverse as Texas, are essential tasks of a state geological agency. In that regard the Bureau has maintained a consistently high level of activity over the years. The U.S. Geological Survey cofunded two mapping projects of complex volcanic terrains in Trans-Pecos Texas, the Christmas Mountains and Hen Egg Mountain Quadrangles and the Davis Mountains. A significant discovery was made of two previously unrecognized calderas in the Christmas Mountains that are smaller, less silicic, and older than others in the Trans-Pecos magmatic province. A primary objective of the Davis Mountains project is to untangle the complicated stratigraphy of several large-volume ash-flow tuffs and lava flows through detailed mapping, geochemical analysis, and argon 40-39 dating. The new "Geologic Map of Texas" and "Tectonic Map of Texas," to be presented in full color at 1:500,000- and 1:750,000-scale, respectively, are currently both in color-separation. Several out-of-print maps of the Geologic Atlas of Texas series were revised during the year and are ready for redrafting.

In addition to mapping, a variety of other basic-research projects undertaken by the Bureau have direct applications to energy and mineral development and evaluation in the state. Bureau scientists are using a state-of-the-art, three-dimensional seismic data base to detail the structure of buried salt domes in the Green Canyon area of the deep-water northern Gulf of Mexico. Interpretation of the tectonic development of these features will allow the prediction of the location of subtle hydrocarbon traps in this frontier exploration area. A multiyear analysis of upper Paleozoic cyclothemic successions in a 22,000-mi^2 region of the Eastern Shelf and adjacent Midland Basin will culminate in a comprehensive Bureau report in which the latest sequence-stratigraphic concepts are integrated with more traditional subsurface correlations and mapping. In 1988 an investigation of how segments of normal faults link together to form larger faults was begun. The chemical-analytic capabilities of the Bureau's Mineral Studies Laboratory were improved by the recent acquisition of an inductively coupled plasma mass spectrometer (ICP/MS). In an ongoing industry-supported investigation, Bureau chemists are developing a system that uses helium ICP as an ionization source (argon ICP is the conventional source).

Further descriptions of these and other Bureau research projects are provided on the following pages.

Energy Resources Investigations

Petroleum

Geoscience Institute for Oil and Gas Recovery Research

Marcus E. Milling, Institute director; F. Jerry Lucia, Claude R. Hocott, Mark A. Miller, and Edwin B. Neitzel, technical coordinators

The Geoscience Institute for Oil and Gas Recovery Research, established by The University of Texas at Austin and housed at the Bureau of Economic Geology, is composed of a national consortium of universities and other State entities engaged in advanced oil and gas recovery research programs in petroleum engineering, geophysics, and geology. The 21 participating organizations comprise 17 states and represent all major hydrocarbon-producing provinces of the United States. The Institute was established to

- provide a better focus for the public sector's oil and gas recovery research programs,
- develop a unified broad-based constituency to increase and support university and State agency research, and
- identify and coordinate multiuniversity programs with joint industry and U.S. Department of Energy support.

The U.S. Department of Energy's (DOE) Office of Fossil Energy asked the Institute to undertake a study to identify the major technical program elements, research activities, priorities, and costs required to initiate a comprehensive geoscience oil and gas recovery research program. The major goal of the Institute's study was to identify program priorities required for development of new concepts, advanced reservoir models, and technology to maximize recovery of mobile and immobile oil and natural gas resources from existing fields. As recommended by the Energy Research Advisory Board's (ERAB) Solid Earth Sciences Panel, the study focused primarily on shorter term, lower risk research opportunities for improving recovery efficiency from existing fields. However, the study also evaluates and identifies options for longer term, more fundamental recovery research.

In addition, a strategy was developed for integrating the major technical program elements to better relate reservoir geology, petroleum engineering, and development geophysics aspects of oil and gas recovery research. One of the major causes of past research failures, when moving projects from the laboratory to the field-test scale, has been that too narrow a disciplinary approach has been used. A more integrated, multidisciplinary approach permits a synergistic, problem-oriented program for improved recovery efficiencies. This study synthesizes research activities and recommends their priority within the framework of major program elements to be included in the new comprehensive geoscience oil and gas recovery research initiative.

Using information gathered at a series of Regional Technical Forums, the Institute identified six major program elements for development:

- Field Reservoir Frameworks
  The occurrence and distribution of reservoirs and their intrafield variability are controlled by the stratigraphic and structural framework. Targeting development wells to extend field limits, test undrained fault segments, and evaluate deeper pool potential requires establishment of the geological framework of the field. Field framework studies also provide a basis for detailed reservoir characterization.
- Reservoir Characterization for Resource Targeting
  Improved reservoir models delineating patterns of geologic heterogeneities are essential to determine the distribution of reservoir flow units and target remaining mobile oil, immobile oil, and undrained natural gas resources in existing fields for strategically directed infill drilling and recompletion programs.
- Reservoir Performance Prediction
  Quantification of geologic heterogeneity patterns of interwell areas will provide improved reservoir flow models for better prediction of production performance and enhancement of advanced recovery applications.
- Advanced Extraction Technology
  The capillarity, mobility, and miscibility of reservoir fluids are critical properties that control the efficiency of recovery processes. Development of mobility control agents to reduce the effect of reservoir heterogeneity on fluid flow is required for more efficient recovery of mobile and immobile oil resources.
- Stimulation and Completion Technology
  Unswept oil and gas in low-permeability zones provide significant targets for additional recovery. Accurately contacting these pay zones will require improved formation evaluation, well completion techniques, and stimulation methods.

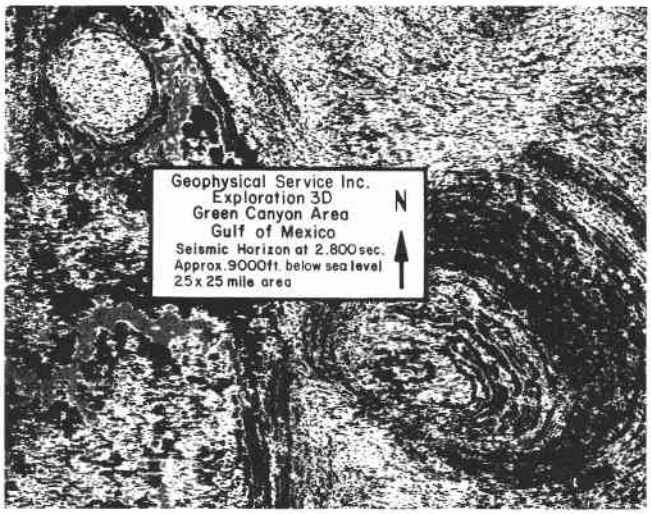
- Resource Assessment, Data Bases, and Technology Transfer
  Characteristics and hydrocarbon reserves and resources for existing fields will be documented. Such a data base will provide a basis for prioritizing and selecting areas for technology deployment and research emphasis. The ultimate success of the advanced geoscience research initiative will depend on how well new concepts and technological developments can be transferred to the operators and service companies. Efficient technology transfer requires effective publications, special seminars and workshops, continuing education courses, and joint cooperative programs with industry.

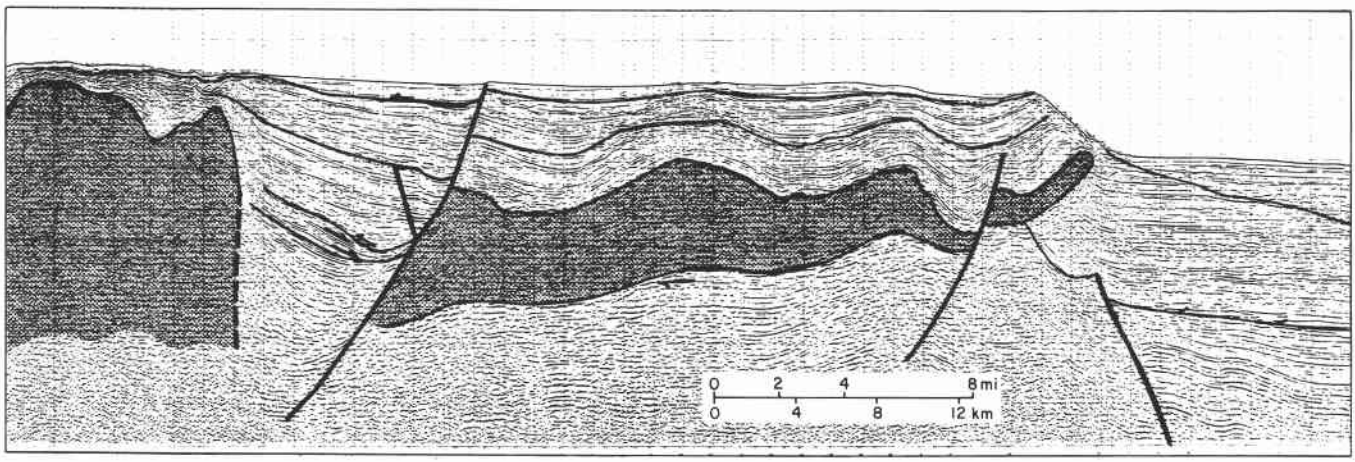
The recommended multidisciplinary research program is aimed at improving efficiencies in the recovery of unswept and uncontacted mobile oil, immobile oil, and untapped gas in existing reservoirs. A principal research goal is the development of technological tools and techniques to provide better understanding of the complexities and variations in reservoirs so that wells can be strategically drilled on a geologically targeted basis, rather than on the customary basis of uniform spacing. Such targeting will improve our ability to place wells at optimal locations to contact undrained reservoir compartments and, therefore, increase recovery at lower cost from existing reservoirs and provide the framework to begin advanced extraction processes. The Institute submitted a draft copy of its Program Summary Report, which included prioritization of research activities, timing, and costs, to DOE in November.

Salt Tectonics on the Continental Slope, Northern Gulf of Mexico

Martin P. A. Jackson, principal investigator; Steven J. Seni

The Texas Higher Education Coordinating Board, under the Advanced Technology Program, funded a 2-year research project to investigate salt tectonics on the continental slope of the northern Gulf of Mexico. Work funded by the project began in September. The deep-water Gulf of Mexico is currently receiving much attention from industry as one of the most promising areas in North America for future petroleum discoveries. Salt structures in this area are the primary control of the distribution of traps for oil and gas. Because little is known of the salt tectonics in the deep Gulf, this topic has great potential as a frontier of scientific as well as economic discovery. Understanding the history of salt migration





A Seiscrop map (upper right) shows the horizontal seismic signature of salt and sediments from the Green Canyon area, Gulf of Mexico. Sediment-filled salt-withdrawal basins are shown by the semicircular areas with an onion-skin texture. Salt structures are the light areas of circular to irregular form with no coherent reflector patterns. A diapir with a circular map expression in the northwestern part of the map area occurs within a thick sediment-filled submarine trough. A large salt sheet (bottom) is shown at the toe of the continental slope in the Green Canyon area. Large anticlines over the salt sheet are related to folding on the upper surface of the sheet. Below the salt sheet, reflectors from layered sediments terminate at the base of the sheet. Sediments below the salt sheet are also folded and faulted. The updip margin of the sheet is bounded by a large counterregional fault.

is important for the petroleum exploration industry because dome growth creates a wide range of subtle traps for migrating petroleum. Technologically advanced seismic studies in the deep-water slope environments and investigations of exposed diapirs in central Iran have recently recognized exotic salt structures such as allochthonous salt tongues and canopies. The ability to predict the location of subtle hydrocarbon traps in this frontier exploration area requires a major advance in understanding this new and radically different type of salt tectonics.

A framework for predicting hydrocarbons in an area of complex salt structures can be established most reliably by understanding the relationships between salt evolution and sediment interactions. An integrated, multidisciplinary approach is necessary for this task because both salt structures and their enclosing sediments must be examined. A key to understanding and predicting the synergistic relationship between salt and sediment lies in deciphering the history of sediment deposition and deformation around the salt structures. Several methodologies will be used, including basin analysis studies that integrate depositional systems, and geohistory analysis and seismic sequence analysis.

The primary source of information that will be used to analyze salt tectonics on the continental slope in the Green Canyon area is a state-of-the-art exploration three-dimensional seismic data base. Geophysical Services, Inc., donated the data base, as well as regional two-dimensional seismic lines. The unique advantage of the three-dimensional seismic grid is that three orthogonal slices through the data volume can be computed and analyzed. In addition to the typical strike- and dip-oriented vertical sections of seismic lines, horizontal data slices can be generated for study. The horizontal seismic sections (seiscrop section, or time slice) are extremely useful for structural mapping of faults and angular unconformities and delineating the geometry of salt structures.

Since September, salt structures have been mapped and seven seismic sequences in the Pleistocene Series have been delineated. Currently, paleontologic data from wells are being integrated with seismic sequence analysis to analyze the timing of salt movement. Preliminary analysis indicates that circular diapirs, irregular large salt massifs, and allochthonous salt sheets all occur on the continental slope in the Green Canyon area of the northern Gulf of Mexico. The updip margins of some of the large allochthonous salt sheets are associated with ramps that form large counterregional normal growth-fault systems. Allochthonous salt sheets typically intrude laterally along shallowly buried regional unconformities. Periods of lateral intrusion were concentrated in the Miocene and the Pleistocene Epochs.

Genetic Stratigraphy, Depositional Systems, Structural Evolution, and Petroleum Exploration Potential: Northwest Gulf of Mexico Continental Shelf

Robert A. Morton, project director; assisted by Richard H. Sams, Robert S. Single, and Alan M. Belasco

This long-term industry-sponsored research program is focused on regional genetic stratigraphy, structure, and energy resources of the Texas portion of the continental shelf and upper slope. The primary data base, which has been gathered during the past 5 years, includes more than 2,000 conventional well logs, numerous paleontologic reports, seismic lines selected from regional grids, scout tickets, and production records. In 1985 an industrial associates group was organized to maintain the research effort and to increase the exchange of information with potential users. Companies supporting the effort in 1988 were Consolidated Natural Gas, Mobil, Standard Oil, Tenneco, and Total Minatome.

In 1988, correlation and quantitative mapping of Plio-Pleistocene stratigraphic units in the East Breaks and western Garden Banks areas were completed, a set of structural cross sections was drafted, and a series of maps depicting structural trends and sandstone distribution was prepared. Featured in the map series are isopach maps of net sand and percent sand for six stratigraphic units and maps illustrating principal depositional features, structural elements, and hydrocarbon plays. By yearend the project was directed toward completing maps and seismic facies interpretations to produce a regional synthesis and report of depositional systems, structural framework, and petroleum resources of Plio-Pleistocene depositional sequences on the outer shelf and upper slope.

A fourth phase of the project was initiated in 1988 involving correlating logs in the West Cameron and western Garden Banks areas and integrating the lithostratigraphic and biostratigraphic correlations into a regional grid of seismic lines. Scheduled for 1989 are a series of maps and cross sections that will complement those prepared for the adjacent shelf and slope.

Depositional Styles of Neogene Slope Systems, Texas Continental Shelf

Robert A. Morton, project director; assisted by Gerald F. Wick

The search for oil and gas in the western Gulf Coast Basin has spanned a period of more than 50 years. During that time, nearly all of the prospective structures at shallow and intermediate depths have been

tested onshore and beneath the continental shelf. Despite the current level of exploration and maturity, additional hydrocarbons undoubtedly exist at greater depths and in deeper water. Both geographic and geologic extensions, however, require an understanding of deep-water sedimentation and recognition of various types of slope systems that offer the greatest future exploration potential. The purpose of this research, funded by the Minerals Management Service, U.S. Department of the Interior, as part of its Studies Related to Continental Margins project, is to compare and contrast the characteristics of slope-related systems in the western Gulf Coast Basin and to develop depositional models that would synthesize their salient features.

Three hydrocarbon-producing slope systems of offshore Texas that are being investigated in detail are (1) lower Miocene (pre-*Siphonina davisi*) strata in State waters of the High Island Area, (2) middle Miocene (*Cibicides opima*) strata of the Galveston Area, and (3) middle Pliocene (pre-*Globoquadrina altispira*) strata of the High Island South Addition Area. A common characteristic of these three systems is that each represents deposition near the paleoshelf margin. Beyond that similarity, preliminary examination suggests that they are distinctly different in their areal distribution, geometry and continuity of sandstones, facies architecture, seismic expression, and relationship to relative sea-level fluctuations within the basin.

During 1988 additional electric logs and paleontological reports were obtained for wells penetrating the objective stratigraphic units. The logs were correlated, and preliminary cross sections were constructed to illustrate the changes in lithofacies and paleoecological zones within the slope systems. These cross sections were integrated with available seismic lines to interpret the history of submarine pediment excavation and subsequent deposition. At yearend maps of net sandstone and percent sandstone were being prepared for each of the stratigraphic units to document depositional patterns and to identify pathways of sediment transport.

Geological Characterization of Reservoirs on University Lands

Noel Tyler and Don G. Bebout, project directors; Graham E. Fogg, Chester M. Garrett, Jr., Edgar H. Guevara, Claude R. Hocott, Mark H. Holtz, Susan D. Hovorka, Charles Kerans, F. Jerry Lucia, Richard P. Major, Stephen C. Ruppel, and Gary W. Vander Stoep; assisted by Thomas L. Cogswell, Janet M. Coleman, Mary M. Crabough, Richard D. Edson, Jr., William M. Fitchen, Andrew P. Czebieniak, Holly J. Lund, F. Leo Lynch, Robert S. Single, and John A. Tenison

The Bureau has been conducting detailed geological and engineering studies on reservoirs on University Lands for more than 4 years with funding from The University of Texas System. Research activities in 1988 included studies of lower Guadalupian San Andres/Grayburg, Silurian-Devonian, and upper Guadalupian Queen reservoirs. The objective of conducting these integrated multidisciplinary reservoir studies is to locate remaining mobile oil in selected reservoirs on University Lands and to provide operators of these reservoirs information that will aid in the more effective recovery of the remaining hydrocarbon resources.

San Andres/Grayburg Reservoirs

Continued study of the Grayburg reservoir of the Dune field, Crane County, involved a quantitative analysis of the production history of infill wells in Section 15 of the Mobil Unit 15/16. Results show that approximately 89 percent of the oil recovered to January 1988 was produced from that 65 percent of the area identified in an earlier Bureau study as containing the major fraction of the oil remaining at the initiation of the infill-drilling program (Report of Investigations No. 168, "Characterization of the Grayburg Reservoir, University Lands Dune Field, Crane County, Texas," by D. G. Bebout and others [1987]). At the end of the current development cycle approximately 7 million barrels of mobile oil will remain in the reservoir, and the major fraction will still reside in the southeast quadrant. A final report of this study is in preparation.

Also in Section 15 of the Dune field, several reservoir simulation experiments have illustrated potential effects of infill drilling on oil recovery efficiency and water/oil ratios. Uncertainty concerning interwell heterogeneity was managed by using the stochastic/geostatistical technique of conditional simulation to generate many different realizations of the spatial distribution of permeability. Selected permeability distributions from the stochastic analysis were then used in the simulation of oil production and waterflooding for different well spacings. Modeling results indicate that with the existing 10-acre spacing of production and injection wells, recovery efficiency in the high-permeability grainstone facies in the zone studied will be no greater than 28 percent. Addition of infill wells in the model to achieve an average well spacing of approximately 2.5 acres has a significant effect, adding 12 to 15 percentage points to the recovery efficiency while maintaining water/oil ratios at moderate levels. Additional funding from Cray Research, Inc., is supporting three-dimensional simulation to provide more realistic estimation of heterogeneity in ongoing modeling of this reservoir.

The geologic and engineering study of the East Penwell San Andres Unit, Ector County, Texas, is now nearly completed and has resulted in the siting of two geologically targeted development wells. Results of part of this research have been published by the Society of Economic Paleontologists and Mineralogists in a Core Workshop volume, and several manuscripts are in preparation as Bureau publications. Study of this San Andres reservoir has led to investigation of production from the overlying Grayburg Formation, where there is no current production at Penwell field. Knowledge of facies geometry, depositional environments, and production patterns in the San Andres Formation has led to interpretations concerning the presence of similar porosity and hydrocarbon saturation in the Grayburg Formation east and downdip of current San Andres production. The operator completed one downdip Grayburg test, and the well produced gas and oil until mechanical damage to the wellbore required that the well be plugged. Additional Grayburg tests are anticipated in the future.

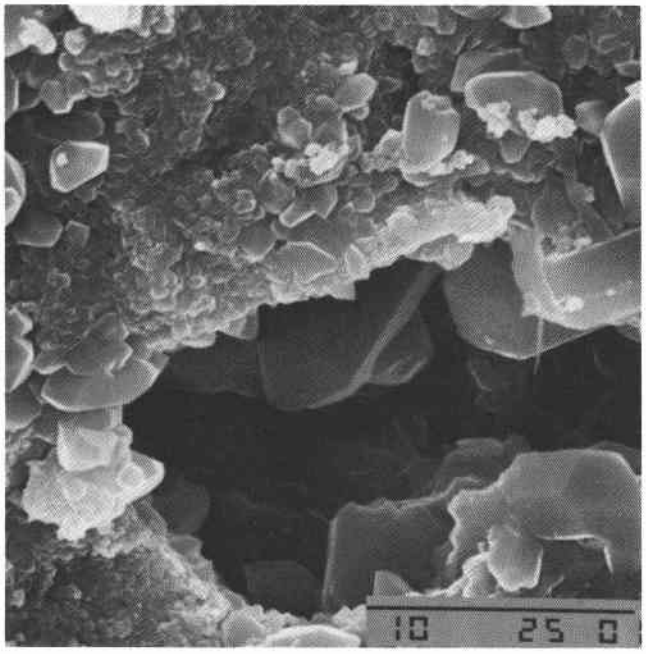
Geologic and engineering study of two units in the San Andres reservoir at Jordan field, Ector and Crane Counties, has identified the effects of geologic heterogeneity on waterflood efficiency. The reservoir has been divided into three petrophysical zones: (1) an upper zone of peritidal facies that is locally porous and permeable, (2) a middle zone of pellet grainstone with moderate interparticle porosity and minor moldic porosity, and (3) a lower zone of diagenetically altered (leached) pellet grainstone and skeletal grainstone with interparticle porosity and high permeability. Production-history plots reveal that many wells have floodwater cycling problems. Injection-profile data indicate that although most wellbores are open to the entire formation most floodwater is injected into the lower zone, and locally significant amounts are injected into the upper zone. Injection in the middle zone is rare, suggesting that this zone is incompletely swept owing to channeling through the more permeable upper and lower zones.

At Taylor-Link West San Andres Unit, Pecos County, geologic and rock fabric/petrophysical studies of both fracture and matrix (interparticle) pore networks provide a simplified reservoir model. Basically, the model recognizes reservoir-quality ramp-crest carbonate grainstones with a high percentage of interparticle porosity in the upper portion of the reservoir, underlain by mud-dominated low-matrix-porosity outer-ramp facies (fusulinid and crinoid-mollusk wackestone facies). Solution-widened fractures and vugs are concentrated in the lower zone as a result of selective meteoric dissolution of secondary evaporite minerals in the outer ramp facies. The grainstone facies is only slightly affected by fracturing, and the fusulinid wackestone facies have throughgoing fracture systems with up to several darcys permeability. Permeability in the grainstone facies is due to the matrix pore system; most permeability in the other facies is due to the fracture system. Calculations of original oil in place demonstrate that most of the producible oil was originally located in the grainstone facies, and about 20 million barrels of unrecovered mobile oil still remain in the reservoir. However, recovery operations are hampered by the need to handle huge quantities of floodwater that is being circulated through the fractured facies, which have high fracture permeability and little oil saturation, and is bypassing the grainstone-bar facies, which contains most of the oil saturation. Consequently, the Taylor-Link Operating Company has made initial attempts at selective completion designed to isolate both the injection and production wells in the more favorable grainstone interval, resulting in significant reductions in volume of water produced without change in the volume of oil produced. With this encouragement, the operator is continuing to modify the waterflood to improve recovery of the 20 million barrels of mobile oil remaining in this field.

Sixty-one million barrels of remaining mobile oil are reported for the Grayburg reservoir of the Farmer field, which is located entirely on University Lands in Crockett and Reagan Counties. Because of this high volume of remaining mobile oil and the low recovery efficiency (12 percent), the Bureau has undertaken an integrated geological and engineering characterization of the reservoir to aid the operators in infill-drilling operations and well completions. The study has been limited to a 5-mi^2 area where operators (Marathon and Unocal) have included in their drilling programs long cores and full log suites through the reservoir section. Six 300- to 450-ft-long cores have been described, and the facies identified from the cores are being calibrated to the logs. Crossplots illustrate a good correlation of porosity from acoustic-log travel time and low-temperature core analysis. High porosity and permeability occur in thin (5- to 15-ft-thick) fine-grained pellet grainstone units in the central part of several upward-fining cycles.

Silurian-Devonian Reservoirs

Study of Silurian and Devonian reservoirs in the Midland Basin and Central Basin Platform areas is continuing with examination of the silicified-limestone reservoir in Amoco's Three Bar field. At least three distinct pore types—skeletal molds, intercrystalline chalcedony micropores, and microfractures—exhibit different permeabilities and spatial distribution. Regional study indicates that



Scanning electron microscope photograph showing intercrystalline and moldic porosity in Devonian chert in Three Bar field, Andrews County.

this reservoir trend extends across more than 250 mi^2 of southwestern Andrews, northeastern Winkler, and northwestern Ector Counties and includes the Dollarhide, Bedford, Block 11, and North Goldsmith fields. Most of the Silurian-Devonian production on University Lands is from similar silicified limestones.

Queen Reservoirs

Study has begun on three unitized areas that produce oil from a Queen sandstone reservoir in McFarland and Magutex fields, Andrews County. Detailed description of two cores from the Magutex field has shown that the reservoir is composed of two fine-grained-sandstone intervals with an average total net pay of 30 ft. Preliminary analysis indicates that permeability and production are controlled by the amount of anhydrite cement present. The two fields have produced 42 of an estimated 151 million barrels of the original oil in place. Sandstone-distribution and log-facies maps suggest that these fields, currently drilled on 40-acre spacing, are highly prospective for a targeted infill-drilling program.

Reservoir Characterization Research Laboratory

Noel Tyler, laboratory director

The Reservoir Characterization Research Laboratory (RCRL) was formed to describe and quantify interwell heterogeneity and its influence on fluid flow in the subsurface. Initiated in 1986, the RCRL is funded by industrial associates. Two reservoir characterization projects are currently under way, both examining low-recovery oil reservoirs of the Permian Basin of West Texas.

Characterization of Spraberry and Dean Reservoirs

Edgar H. Guevara, principal scientist; George R. Coates, Robert L. Folk, and Gary W. Vander Stoep; assisted by William B. Wethington, John L. Garber, and Karen L. Herrington

Studies of deep-water, terrigenous-clastic oil reservoirs in the Midland Basin, West Texas, continued in the second research year of the RCRL. Investigations were conducted on Spraberry and Dean reservoirs (Lower Permian, Wolfcampian and Leonardian), with the support of ARCO, Exxon, Mobil, Standard, and Texaco. The Spraberry/Dean play contained 10.6 billion barrels of oil originally in place (OOIP), but because recovery efficiencies are generally less than 10 percent of the OOIP, about 10 billion barrels of nonresidual, mobile oil will remain after primary and secondary recovery at existing levels of development. Approximately 1 billion barrels of mobile oil are the target for additional, nontertiary recovery. RCRL studies will help define development strategies aimed at reserve growth in these highly heterogeneous, compartmentalized, and low-recovery reservoirs.

Continuing RCRL studies of Spraberry reservoirs consisted of formation evaluation and analysis of fractures using oriented cores and state-of-the-art open-hole and cased-hole log suites. The mineralogical and elemental compositions of selected core samples were determined using petrography, X-ray diffraction, and mass spectrometry. Log data and elemental and mineralogical compositions were used to calculate the petrophysical properties and fluid saturations of the reservoirs. Additionally, oriented cores and well logs, among them resistivity images of the borehole walls, permitted assessment of the occurrence and orientation of fractures. Core and log data confirm that the main reservoirs are sandstones and siltstones in the upper part of upward-coarsening and upward-thickening sequences of the lower and upper Spraberry and that fracture detection, and the differentiation between natural and drilling-induced fractures, is still ambiguous using well data.

Oil reservoirs in the Dean Formation were delineated basinwide and in local study areas. They are very fine grained sandstones and siltstones that form part of laterally extensive, generally upward-fining and upward-thinning intervals (operational

units). Structural, isopach, isolith, and porosity maps of the operational units were constructed using core and normalized gamma-ray and neutron logs. These data indicate that the operational units onlap the basin margins and paleobathymetric highs related to the Horseshoe Atoll and that beds of sandstone and siltstone in the operational units are laterally discontinuous, representing mostly submarine-fan channel and associated facies. Basinwide oil-field distribution and local production data show that reservoir stratigraphy is a major control on hydrocarbon occurrence and recovery in Dean reservoirs. Targets for reexploration and extended development are partly drained and untapped reservoir compartments along sandstone and siltstone depositional axes having relatively high porosities.

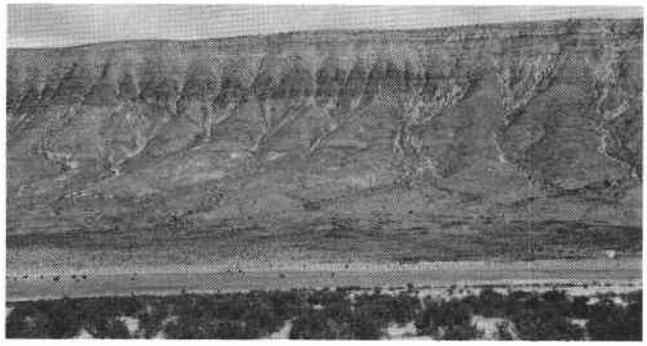
Characterization of San Andres and Grayburg Reservoirs

Charles Kerans, principal scientist; F. Jerry Lucia, Graham E. Fogg, H. Seay Nance, and Mark H. Holtz; assisted by Robert S. Single and Michael R. Rosen

This new 2-year project, initiated in September to study San Andres and Grayburg reservoirs, has received strong support from the oil industry. Participating industrial associates at the end of 1988 were Amoco, ARCO, Chevron, Exxon, Marathon, Mobil, Shell, Texaco, and Unocal. The goal of San Andres-Grayburg studies is to develop and apply new methods for more efficient recovery of the vast resource of mobile and residual oil that will remain in the complex and highly stratified restricted platform carbonates of the Permian Basin at abandonment.

The focus of this project is to address the critical problem of vertical and interwell heterogeneity that is widely accepted to be the major cause of low recovery efficiency in these Permian carbonate reservoirs. Interwell heterogeneity will be modeled to offer predictability through the integration of outcrop and subsurface geological, geostatistical, and engineering studies. Outcrop studies are being conducted in the Guadalupe Mountains of New Mexico, where the 17-mi-long dip-oriented Algerita escarpment exposes a complete tidal-flat to outer-ramp-slope cross section. Detailed geologic and permeability mapping, a multiwell coring and logging program, and geostatistical analysis will form the basis for quantitative characterization at facies/flow-unit continuity that will be used to condition reservoir simulation studies.

Subsurface studies of San Andres reservoirs of the Permian Basin will integrate all available core and engineering/production data to form a basis for outcrop/subsurface comparison. Geostatistical models of flow-unit continuity and simulators conditioned by outcrop data will be applied to reservoirs to develop optimal geologically targeted infill sites and selective completion intervals. Two- and three-dimensional simulators calibrated to the outcrop will be run on the Cray supercomputer housed at the UT System Center for High Performance Computing at Balcones Research Center.



San Andres Formation outcrops of the Algerita escarpment, Guadalupe Mountains, are being examined by the Bureau's Reservoir Characterization Research Laboratory to improve the understanding of critical aspects of interwell heterogeneity and facies control on reservoir quality in San Andres and Grayburg carbonates.

A Geologic-Based Estimate of Oil Reserve Growth in Texas

Noel Tyler and Robert J. Finley, project directors; William A. Ambrose, Mary L. W. Jackson, and Mark H. Holtz

The Bureau has estimated that 35 billion barrels of unrecovered mobile oil exist in Texas. Geologically based infill drilling and improved waterflooding that selectively target oil in poorly drained or uncontacted compartments of internally complex reservoirs can recover much of this resource.

In 1987, the U.S. Department of Energy funded a joint study by the Bureau and ICF-Lewin to characterize the potential and economic feasibility of oil reserve growth of selected volumetrically important oil plays in Texas. The San Andres/Grayburg South Central Basin Platform play, a major carbonate play in the Permian Basin, and the Frio barrier-strandplain play, a large sandstone play in the Gulf Coast, were selected for reserve-growth analysis through strategic infill drilling. These plays collectively contain 14.5 billion barrels of oil in place, of which 4.8 billion barrels of remaining mobile oil in place is potentially recoverable through infill drilling and secondary recovery techniques.

The Grayburg reservoir in Dune field, located in the South Central Basin Platform play, was selected for detailed study because the geological and reservoir engineering studies had already been conducted for

the Bureau's University Lands project. The distribution of permeability calculated in that study formed the basis for the establishment of pay-continuity functions that relate reservoir continuity to horizontal distance between existing wells. Continuity functions were developed on a facies-specific level. These functions formed the basis for projection of the strategic infill production potential to the rest of Dune field and the entire play.

The Bureau also characterized the infill potential of the 41-A reservoir in West Ranch field, located in the Frio barrier-strandplain play in the Gulf Coast. Although barrier-island reservoirs in this play are much more homogeneous and have greater recovery efficiencies than carbonate reservoirs in the Permian Basin, they also contain poorly drained compartments in tidal-inlet and flood-tidal delta facies that pinch out into low-permeability lagoon mud. Previous work by the Bureau had documented the distribution of these heterogeneous barrier-island facies in the 41-A reservoir. Current investigations by the Bureau have resulted in characterizing the reserve-growth potential of the reservoir by establishing pay-continuity functions for each of the major facies present. These functions were based on statistical analysis of lateral variation of Kh (permeability multiplied by pay thickness) between adjacent wells. The amount of oil that can be recovered through strategic infill drilling in the 41-A reservoir was established by estimating the volume of each major facies in the reservoir and then applying separate pay-continuity functions to each of them. A similar procedure was used to extrapolate amounts of recoverable oil to the entire play.

Preliminary results indicate that appreciable amounts of oil can be added to the reserve base in Texas through geologically based infill well development from 20-acre down to 10-acre spacing. In particular, many carbonate reservoirs with low recovery efficiencies such as Dune can be economically drilled down to 5-acre spacing in some areas where new infill wells can contact several poorly drained compartments within heterogeneous facies.

Estimation of Economically Recoverable Unswept Mobile Oil

Noel Tyler and Robert J. Finley, principal investigators; Mark H. Holtz, William A. Ambrose, Nancy J. Banta, Chester M. Garrett, Jr., H. Seay Nance, Gary W. Vander Stoep, and W. Gerald White; assisted by Alicia D. Simpkins and Peter B. Stokes

This project, conducted jointly by the Bureau and ICF-Lewin, is funded by the Bartlesville Project Office of the U.S. Department of Energy. The aim of the study is to characterize the nature and quantify the magnitude of the mobile oil remaining in Texas oil reservoirs and to assess the potential for economic recovery of a significant volume of this resource base.

The mobile oil project has expanded the Bureau's original data base of 450 of the most productive reservoirs in the state to include reservoirs that have produced more than 5 million barrels cumulative production as of January 1988 as well as other select West Texas reservoirs undergoing secondary and tertiary oil recovery. This expanded data base includes a total of 1,100 Texas oil reservoirs. These additional reservoirs have been assigned to plays established in the Bureau's "Atlas of Major Texas Oil Reservoirs," by W. E. Galloway and others (1983), and production data for all reservoirs have been updated through 1986.

As part of this study, a classification system that semiquantitatively categorizes reservoirs on the basis of their styles of vertical and lateral heterogeneity has been developed. This classification system, together with the geological, engineering, and volumetric attributes of reservoirs included in the study, will be used by ICF-Lewin to determine, using industry-standard economic models, the economic recovery potential of the remaining mobile oil resource in Texas. The project will be completed in June 1989.

Accurate Modeling of Fluid Flow in Hydrocarbon Reservoirs and Aquifers with Scale-Averaged Rock Properties

Larry W. Lake, principal investigator (Center for Enhanced Oil and Gas Recovery Research, Department of Petroleum Engineering); Graham E. Fogg

This 2-year research project, funded by the Texas Higher Education Coordinating Board, addresses the problem of estimating scale-averaged rock properties for input into digital simulation models of subsurface fluid flow in aquifers or petroleum reservoirs. A fundamental deficiency in subsurface fluid-flow modeling technology severely hampers the construction of realistic models: the introduction of errors during averaging of permeability data. Even when detailed descriptions of heterogeneous reservoirs and aquifers are available, limitations of even the most powerful supercomputer dictate that this information (usually permeability) be averaged over finite blocks of the simulation model, yet no practical, proven methods exist to perform this averaging without incurring serious errors in simulated fluid-flow fields. This research, which began in September, is aimed at developing methods for estimating accurately the

effective values of permeability and relative permeability (that is, pseudofunctions) for simulator blocks that represent heterogeneous geologic materials.

Stochastic Simulation of Fluid Pathways in Petroleum Reservoirs and Aquifers

Graham E. Fogg and Richard D. Edson, Jr.; assisted by Andrew P. Czebieniak

Funded by Cray Research, Inc., this 1-year program was conducted (1) to develop efficient computer algorithms for stochastically simulating the three-dimensional spatial pattern of hydraulic properties in aquifers and petroleum reservoirs and (2) to apply these algorithms to a complex reservoir problem. The stochastic approach to reservoir description has been used extensively in the Bureau's project Geological Characterization of Reservoirs on University Lands and has proven to be an effective method for quantification of the complexity of reservoir architecture as well as its uncertainty in the context of reservoir simulation models. Three techniques for performing stochastic simulation were implemented and tested on the Cray supercomputer, housed at the UT System Center for High Performance Computing at Balcones Research Center: matrix decomposition, turning bands, and the fast Fourier transform methods. Despite extensive optimization of the matrix decomposition program, it yielded the slowest execution times. The turning bands and fast Fourier transform methods, though slightly less accurate than matrix decomposition, yielded fast execution times and efficient usage of computer memory for large (more than 10,000 blocks) problems. Use of the turning bands program for three-dimensional simulation of permeability in a section of the Dune field on University Lands is providing the basis for realistic simulation of fluid movement in this complex reservoir.

Gas

Geological Investigations of Low-Permeability Gas Sandstone Reservoirs

Shirley P. Dutton and Robert J. Finley, principal investigators; Robert W. Baumgardner, Jr., Karen L. Herrington, Stephen E. Laubach, and Robert S. Tye; assisted by Sabine C. Boardman, Timothy N. Diggs, and Thomas E. Hoak

Since 1982 the Gas Research Institute (GRI) has supported geological investigations designed to develop knowledge necessary to efficiently produce low-permeability, gas-bearing sandstone. As part of that program, the Bureau has been conducting research on the Lower Cretaceous Travis Peak (Hosston) Formation, a low-permeability sandstone in East Texas, North Louisiana, and southern Mississippi. In 1988, research was extended to include the Jurassic Cotton Valley Group in East Texas and preliminary assessment of sandstones in North Texas, New Mexico, Colorado, and Wyoming. This effort is part of a broader program designed to increase the understanding and ultimate utilization of unconventional gas resources through integration of geology, log analysis, and reservoir engineering. At present, many low-permeability, gas-bearing sandstones are not being efficiently evaluated, hydraulically fractured, or produced because of a lack of appropriate technology to stimulate development of the gas resource at competitive prices.

Research in 1988 focused on evaluation of data from a GRI-operated test well in East Texas that was drilled in the Travis Peak in 1987, the second Staged Field Experiment (SFE) well. In addition, regional studies of Travis Peak diagenesis, stratigraphy, and structure continued. Other research efforts included locating and drilling the third SFE well to study the Travis Peak and Cotton Valley, and completing an in-depth review of the geology and reservoir characteristics of selected low-permeability sandstones in four western basins that are potential study areas for the fourth SFE well.

Geological research objectives for the Travis Peak study based on the second SFE well included developing an understanding of the depositional systems of the reservoirs, determining the diagenetic history, and evaluating the effects of sedimentologic and diagenetic factors in governing the physical properties of reservoir and fracture-barrier rocks. Another objective was to characterize fractures in reservoir rocks and to develop and test models of fracture formation that can be used to predict fracture occurrence and the effects of fractures on reservoir stimulation operations.

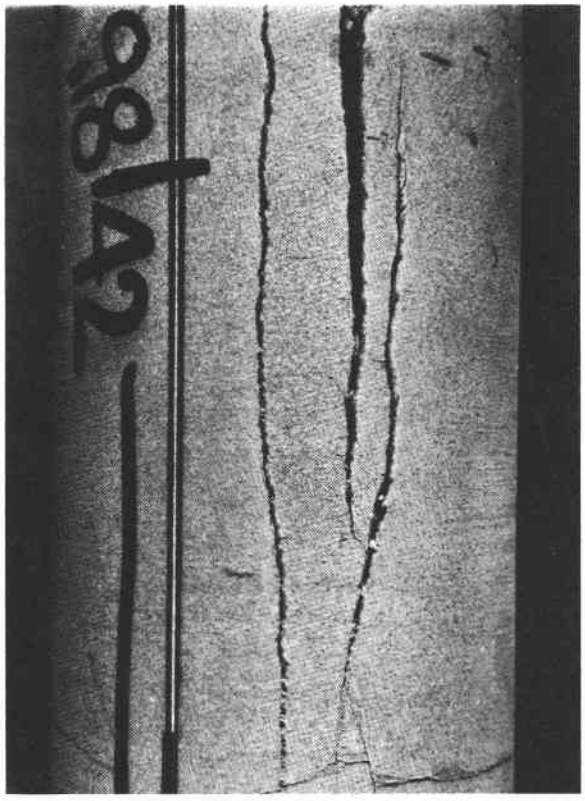
Stratigraphic studies are progressing along two major research lines—regional basin analysis and detailed field studies. A detailed study of North Appleby field established a foundation upon which predictions about reservoir geometry, the degree and type of diagenesis that the reservoir has undergone, and natural fracture occurrence can be made. Broad, tabular reservoirs (10 to 45 ft thick; 3 to 5 mi wide) were deposited by braided- to meandering-fluvial systems. Reservoirs seals and internal fluid-flow barriers consist of mudstones and porosity-occluding

quartz cement. Geometry and quality of Travis Peak reservoirs vary as a function of the depositional system, degree of diagenesis, and natural fracture development. Reservoirs at the top of the formation are thin and separated by mudstones and have few natural fractures. Productive sandstones at the base of the formation, however, are thicker and more sand rich, and are naturally fractured.

Studies of diagenesis focused on the relationship between petrophysical properties and petrographic parameters such as cementation, clay content, and grain size. The overall decrease in permeability with depth in the Travis Peak results from a variety of factors. In fluvial sandstone, the decrease is primarily the result of greater amounts of quartz cement in more deeply buried rocks. This may be related to a second phase of quartz dissolution and reprecipitation marked by stylolite formation. These results are useful for understanding permeability variation in the Travis Peak, but they also show that subtle differences in diagenetic history can produce important variations in petrophysical properties. These differences would be difficult to predict without petrographic information.

Natural fractures may enhance accumulation and production of hydrocarbons in some Travis Peak reservoirs, and knowledge of natural fracture characteristics is important for fracture treatment design. Structural studies in 1988 involved in-depth analysis of natural fractures in core from the second SFE well, including documentation of fracture shapes, petrographic analysis of microstructures, thermometric analysis of fluid inclusions in fracture-filling minerals, and correlation of fracture characteristics with rock mechanical properties.

Fractures in Travis Peak sandstone are locally open, with *subsurface* widths of as much as 0.2 inch at depths of 9,800 ft in the second SFE well. The contrast between high in situ permeabilities measured in well tests in some fractured zones in the second SFE well and low permeabilities measured in core suggests that fractures can be an important component of reservoir permeability. Petrographic studies indicate that fracture development was a consequence of diagenetic processes, including fluid migration and quartz cementation, that also resulted in low matrix permeability. Detailed (1:1) mapping of fractures in more than 300 ft of core shows that isolated, planar fractures with low aspect ratios occur in sandstone with less well developed quartz cement and low stiffness. Closely spaced, multistranded to dendritic fractures with high aspect ratio *and* narrow, isolated fractures occur in the sandstone with more extensive quartz cement and high stiffness. The most fractures are in fluvial sandstone with extensive quartz cement. Predictions of natural fracture characteristics based on models of fracture formation were incorporated in hydraulic fracture treatment design for the second SFE well.



Natural, open extension fracture in Travis Peak sandstone core from a depth of 9,842 ft in the second Staged Field Experiment well in East Texas. Such open fractures can enhance reservoir permeability in low-permeability gas sandstones. Maximum width of this fracture is 0.2 inch.

Many problems in exploiting reservoir fractures stem directly from difficulties in characterizing fracture orientation, geometry, width, and style. Whole core provides the most direct information on fractures and their relation to reservoir rock, but core recovery in fractured rock is commonly poor, and core orientation methods may fail. However, geophysical logs that image the borehole wall can provide information on some critical aspects of reservoir fractures. To improve fracture characterization, a comparative study of core fractures and fracture-imaging logs was begun. Logs used in this study include the Formation Microscanner, an electrical imaging tool, and the acoustic borehole televiewer. Results show that although these logs are useful adjuncts to core-based studies of reservoir fractures, fracture studies based on logs alone still have many drawbacks.

Studies of stress direction and stress magnitude continued in 1988. Geological studies demonstrated that borehole breakouts and some drilling-induced fractures are reliable indicators of stress anisotropy in the Travis Peak. Studies are under way to evaluate

the mechanisms of borehole breakout development and to evaluate borehole breakouts as indicators of stress magnitude. Results of these studies could significantly improve hydraulic fracture treatment design by simplifying and reducing the cost of stress profiles.

Geologic characterization of several fields in East Texas was undertaken to locate a site for the third SFE well. The objectives of the third SFE well include testing diagnostic techniques and models of hydraulic fracture treatment developed in previous SFE wells. An objective of the third SFE is to test geologic, engineering, and log analysis concepts developed in conjunction with the first two SFE's in a new area that has geologic characteristics similar to those in the Travis Peak. Consideration of these factors resulted in selection of the Taylor Sandstone and vertically adjacent shales of the Cotton Valley Group, Waskom field, Harrison County, as the site for the third SFE. The SFE well was drilled in the fall to a total depth of 9,600 ft, and more than 360 ft of core were obtained from the Travis Peak Formation and Cotton Valley Group.

Geologic and engineering data on selected formations were compiled to provide a basis for siting the fourth SFE well. The objective of the fourth SFE well is to extend and apply, in a new area, techniques for the engineering, geological, and geophysical characterization of low-permeability sandstone reservoirs that were developed during drilling and experimentation in SFE wells 1 through 3. Four formations in four basins were chosen for study from an initial group of 183 formations on the basis of criteria that include the relevance of problems involved in gas production to the goals of the GRI Tight Gas Sands program. The geologic units chosen are the Abo (Permian Basin), Cleveland (Anadarko Basin), and Frontier Formations (Green River Basin), and the Mesaverde Group (Piceance Basin).

Research on low-permeability, gas-bearing sandstones in 1989 will include testing and evaluating the third SFE well and continued testing and analysis of information from previously drilled GRI research wells. Local depositional systems studies will contribute to a comprehensive model of regional depositional systems and reservoir potential of the Travis Peak Formation and the Taylor Sandstone of the Cotton Valley Group in East Texas. Petrographic work will continue to explore the relationship between petrophysical properties and petrographic parameters. Structure and diagenetic results will contribute to a comprehensive model for the evolution of the physical properties of low-permeability sedimentary rocks. In addition, geological characterization of low-permeability sandstone in western basins will help define research objectives for the fourth SFE well.

Atlas of Major Texas Gas Reservoirs; Analysis of Gas Reservoir Heterogeneity

Robert J. Finley, project director; Don G. Bebout, L. F. Brown, Jr., Shirley P. Dutton, Chester M. Garrett, Jr., H. Scott Hamlin, Elisabeth C. Kosters, Stephen C. Ruppel, Steven J. Seni, and Noel Tyler; assisted by Nancy J. Banta, Holly J. Lund, Javier Luna-Melo, William E. Schramm, and Peter B. Stokes

The Gas Research Institute and the Bureau have funded this project to assemble and publish geological and engineering data for onshore gas reservoirs in Texas that have produced more than 10 billion cubic feet (Bcf) of gas. Approximately 2,000 reservoirs meet this criterion. Of those reservoirs, about one-third have produced more than 30 Bcf, together accounting for 85 percent of the total cumulative production.

These reservoirs have been grouped into 73 plays primarily on the basis of geological parameters such as age, lithology, formation, reservoir genesis, trapping mechanism, petrophysical properties, and geographic location. The Gulf Coast, by far the largest gas-producing province in Texas, contains 30 of these plays, and 60 percent of the production from this province is from the 10 plays of the Frio Formation. Nineteen of the Texas gas plays are in West Texas, where the largest plays are the Silurian-Devonian and Ellenburger carbonates of the Delaware and Val Verde Basins and Upper Pennsylvanian and Lower Permian Canyon sandstones of the northern Val Verde Basin. In East Texas 11 plays have been identified, and 37 percent of the production is from Lower Cretaceous Glen Rose, Pettet, and Rodessa limestones. Eight plays have been defined in the Texas Panhandle; however, 70 percent of the production is from the two largest reservoirs—Hugoton and Panhandle. North-Central Texas reservoirs are grouped into five plays, of which the Pennsylvanian (Bend) conglomerate play dominates.

These data will be published in 1989 as an atlas similar to the Bureau's 1983 "Atlas of Major Texas Oil Reservoirs." It is anticipated that this atlas will serve as a starting point for future regional studies of gas reserve growth within plays or provinces and for site-specific studies to improve performance of individual reservoirs.

Geological Research for Gulf Coast Co-Production Program

Noel Tyler, project director; William A. Ambrose and David W. Koppenaal

The Gulf Coast Co-Production program, funded by the Gas Research Institute, is designed to improve

hydrocarbon production from hydropressured gas reservoirs that have been abandoned or have begun to water out. Wells in watered-out gas reservoirs are usually shut in because of unfavorable economic conditions such as low gas-production rates and brine-disposal problems.

Previous studies by the Bureau indicate that large volumes of gas in the Frio 1-A reservoir in Northeast Hitchcock field, Galveston County, can be economically produced through co-production, requiring the disposal of approximately 22,500 barrels of brine per day collectively in three disposal wells. As a follow-up study, the Bureau determined the best sands in the overlying Miocene Series in Northeast Hitchcock field for disposal of these brines. By studying Miocene depositional units in Northeast Hitchcock field and the surrounding area and by documenting the brine-injection potential of Miocene sands in nearby fields, the Bureau selected four lower Miocene barrier-island sands, each 50 to 110 ft thick, for brine disposal. Factors considered in selection of these sands were sand-body continuity, thickness, and brine-disposal history.

A brine-disposal well was drilled in Northeast Hitchcock field to intersect the thickest portions of the four potential brine-disposal sands. The Bureau provided detailed geologic descriptions of the three sands that were cored. These descriptions were supplemented by a variety of other data such as permeability and porosity distribution, textural variations, clay mineralogy, and Frio-to-Miocene fluid compatibility. A review of all available geologic and engineering data led to the selection of the lower Miocene 6,150 ft sand for brine disposal in Northeast Hitchcock field. Results have fulfilled expectations for disposal of large volumes of brine; the 6,150 ft sand, which contains homogeneous, high-permeability barrier-core and shoreface sands, has received more than 5,000 barrels of brine per day since October 1987. Other Miocene barrier-island sands, buried at depths from 2,800 to 4,200 ft, are also being considered for future up-hole brine disposal in the Northeast Hitchcock brine-disposal well.

Geologic Studies of Geopressured-Geothermal Resources in Texas

Noel Tyler, project director; H. Scott Hamlin, Charles W. Kreitler, Regina M. Capuano, and M. Saleem Akhter

The ongoing objectives of this U.S. Department of Energy-funded program are to determine the resource base and commercialization potential of deep geopressured-geothermal aquifers along the Texas Gulf Coast. In 1988 long-term production testing of the Pleasant Bayou geopressured-geothermal test well in Brazoria County was initiated. The well is currently flowing at rates between 10,000 and 20,000 barrels per day. An electrical-energy conversion system was constructed at the well site to test the economic feasibility of geothermal energy production. An additional energy source is the natural gas dissolved in geopressured waters.

Detailed geologic characterization of the Pleasant Bayou geopressured-geothermal reservoir was completed in 1988. The geometry, lateral continuity, and internal heterogeneity of this deep (14,600-ft) sandstone in the Frio Formation were carefully mapped using geophysical logs from closely spaced wells. Porosity and permeability data from core samples supplemented log analysis. The total effective, or interconnected, pore volume of the Pleasant Bayou reservoir was calculated to be 6.2 to 6.6 billion barrels. Geologic characterization formed the basis for constructing models for use in computer simulations of the reservoir, which enable prediction of long-term production performance.

As production data from the test well began to be generated late in 1988, a program of hydrologic and geochemical analysis of the geopressured flow system at Pleasant Bayou was initiated. Fluid pressures and flow rates are being used to evaluate reservoir properties such as boundary conditions, recharge mechanisms, and long-term producibility. The chemical compositions of produced liquids and gases are sensitive to changes in fluid source areas and fluid-rock interactions. Geochemical techniques are especially important for analyzing the quantity and composition of light hydrocarbons dissolved in the hot brine. Integration of geologic, hydrologic, and geochemical analyses will enable verification of fluid sources, delineation of flow patterns, and estimation of ultimate resource potential at Pleasant Bayou.

An Assessment of the Natural Gas Resource Base of the United States

Robert J. Finley and William L. Fisher, project directors; Steven J. Seni, Stephen C. Ruppel, W. Gerald White, Walter B. Ayers, Jr., Shirley P. Dutton, Mary L. W. Jackson, and Nancy J. Banta

An assessment of the volumes of technically recoverable and economically accessible natural gas in the resource base of the United States was prepared for the U.S. Department of Energy's Office of Policy, Planning, and Analysis. The study utilized resource estimates of the Potential Gas Committee (PGC), the

U.S. Geological Survey (USGS), and the Minerals Management Service (MMS) and disaggregated and combined these data with Bureau estimates of reserve growth in gas reservoirs, a nontraditional resource increment. Results formed a comprehensive estimate of natural gas available in seven categories of conventional supplies and three categories of unconventional supplies in the lower 48 states. The Bureau study was funded by a subcontract with Argonne National Laboratory who, together with ICF-Lewin, provided supplementary data and evaluation to the assessment. The study incorporated the judgments of a Review Panel, consisting of 17 resource analysts, economists, geologists, and engineers familiar with natural gas resource issues. This group, which represented the oil and gas industry, government, and other private organizations, helped guide the study and estimated the volumes of gas available at wellhead prices at less than $3.00/thousand cubic feet (Mcf) and $3.00–$5.00/Mcf (all prices expressed in 1987 dollars).

The assessment included all major categories of the domestic natural gas supply ranging from proved reserves to undiscovered resources. Existing estimates of natural gas resources were found to be based on different methods and not always to include the same segments of the total resource base. These estimates were disaggregated by producing region and by type of resource so that similarities and differences between available natural gas resource estimates could be better determined.

Included in the project was a first-ever assessment of the potential for nonassociated gas reserve growth in known fields as a source of future gas reserve additions. The Bureau evaluated some 300 producing trends, termed plays, containing data on more than 10,000 fields in the lower 48 states. By assigning depositional systems to each play and by evaluating their related degree of geologic complexity, the potential distribution of incremental, uncontacted natural gas resources was estimated. About 90 percent of the conventional estimated ultimate recovery of known fields in five producing trends (Rocky Mountain, Permian Basin, Midcontinent, Gulf Cenozoic, and Gulf Mesozoic) was assessed, and a reserve growth resource of 119 trillion cubic feet (Tcf) was estimated. This resource includes expected reserve growth of inferred reserves (USGS) and probable resources (PGC), which represent the traditional addition of reserves by extension and deeper pool drilling. Gas reserve growth will be achieved through strategically directed drilling and well recompletion aimed at untapped reservoir compartments and reservoirs bypassed in existing wells. Nearly half of this resource, 56 Tcf, was judged by the Review Panel to be recoverable at a wellhead price of less than $3.00/Mcf (1987$).

In total, a technically recoverable natural gas resource of 1,059 Tcf was defined in the lower 48 states. Among the conventional gas sources, 800 Tcf of reserves, inferred reserves/probable resources, reserve growth potential, and undiscovered resources were delineated in seven categories. Recovery potential at less than $3.00/Mcf was estimated at 495 Tcf. Unconventional reservoirs were estimated to contain 259 Tcf of resources, 88 Tcf of which were judged recoverable at less than $3.00/Mcf. All recoverability was defined on the basis of current technology. The total lower 48 resource at less than $3.00/Mcf of 583 Tcf represents a significant volume of moderate-cost natural gas resources that can be developed to meet the historical uses of natural gas as a fuel and meet expanded use for combined-cycle electrical generation, cogeneration, gas cooling, and other applications that could result in deferment of some of our increasing national dependence on imported oil. Whereas additional natural gas resources are located in Alaska (129 Tcf), this potential supply largely lacks transportation to end-use markets.

The assessment provides a comprehensive look at all major categories of natural gas reserves and resources likely to contribute to domestic supplies in the near to intermediate term. In all cases, a conservative view was taken of technical recoverability as well as the total resource accessible at different price ranges. This was particularly true of unconventional resources, for which the resource base is much greater than the volumes of recoverable gas incorporated in the assessment. Future studies of actual deliverability should find this study to be an important starting point.

Assessment of Gas Resources for Secondary Gas Recovery Technology

Robert J. Finley and Noel Tyler, project directors; Mary L. W. Jackson and William A. Ambrose

The purpose of this project, which is in its second and final year of funding by the Gas Research Institute, is to evaluate geologically based infill drilling and recompletion of bypassed gas zones as sources of increased gas reserves that can be produced at competitive prices.

Three reservoirs from two fields, La Gloria field in Jim Wells County and Julian North field in Kenedy County, were selected for detailed geologic characterization. La Gloria field is representative of the clastic, fluvial South Texas Frio gas play, the second

most productive nonassociated gas play in Texas. As an example from a different depositional environment, Julian North field was selected from the deltaic South Texas Frio play, also one of the top producing gas plays on the Texas Gulf Coast. Although these are mature plays, the highly complex sand-body architecture of Frio fluvial and deltaic sandstones contains numerous partially isolated compartments that remain to be tapped.

During 1988, the project focused on detailed geologic characterization of the Brooks and Jim Wells reservoirs in La Gloria field and the I-92 reservoir in Julian North field. Depositional-facies and net-sand-thickness maps clearly indicate the differences in depositional style between the two environments. Fluvial-channel systems in La Gloria field are dip-elongate, sinuous belts separated by sand-poor levee and floodplain deposits. In contrast, thin, upward-coarsening, strike-parallel sandstone sheets characterize the Julian North barrier-bar and reworked delta-front facies.

Prospect maps generated by combining net-sandstone-thickness maps with net-mudstone-interlayer-thickness maps delineate areas with potential for infill completion. By integrating lateral reservoir heterogeneity, vertical reservoir heterogeneity, distribution of existing perforations, and field structure, opportunities for infill completions were identified for the Jim Wells reservoir. This methodology can be used in any multilayered reservoir to help outline poorly drained or undrained reservoir compartments. Coordinated engineering and economic analysis are being conducted by ICF-Lewin Energy.

Secondary Gas Recovery—Methodology to Increase Gas Reserves in Conventional Gas Reservoirs

Robert J. Finley, project director; Lee A. Jirik and Shirley P. Dutton; assisted by Timothy N. Diggs

This study, incorporated with previous work on co-production of natural gas and water and funded by the Gas Research Institute, began in late 1987 and was completed this year. The study focused on initial development and testing of methods used to maximize recovery from conventional gas reservoirs in mature fields. Advanced geological characterization methods were used to identify untapped compartments within established reservoirs and to evaluate bypassed gas reservoirs in existing wells. New approaches to the interpretation of recently introduced logging tools were used to evaluate bypassed gas-bearing zones within producing intervals. The integration of these techniques resulted in the selection of several reservoirs as candidates for recompletion.

During 1988, the project focused on Seeligson field, Jim Wells and Kleberg Counties, South Texas, which was studied in cooperation with Sun Exploration and Production Company. Seeligson field contains a Sun-operated unit that produces gas from multiple, stacked fluvial-deltaic reservoirs in the Oligocene Frio Formation. The productive section, containing more than 30 reservoirs, is at depths of 4,000 to 6,300 ft. The stacking of fluvial and fluvial-deltaic facies at Seeligson field and the trapping of hydrocarbons on the downthrown sides of synsedimentary faults are characteristic of many producing fields in the prolific, gas-prone South Texas region.

The Bureau's efforts focused on approximately 9 mi^2 in the east-central part of the Seeligson unit. The stratigraphic framework was established with a grid of cross sections that illustrate lateral variability in the fluvially dominated reservoir sandstones. Net-sand-isopach and log-facies maps were prepared for more than 30 unit reservoirs to delineate depositional environments. Bypassed gas zones were identified in 14 wells where thermal-decay-time (TDT) logs were run, and 5 of those wells were selected for digital cased-hole sonic logging. Zones 15 and 18-C were ultimately selected for detailed geologic evaluation.

Zones 15 and 18-C have been largely developed as though they were homogeneous, continuous reservoirs. However, heterogeneities within both zones were documented by the Bureau using advanced geological characterization methods. In Zone 15, four separate genetic units were identified and mapped in detail within the study area. Zone 18-C was found to consist of two separate genetic sandstones. By integrating geological findings with detailed production and well histories, as well as results of the cased-hole evaluation program, wells were identified where bypassed or compartmentalized gas might be found. The Bureau presented recompletion recommendations to Sun in mid-1988.

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

Robert J. Finley, Edgar H. Guevara, and L. F. Brown, Jr., coprincipal investigators; Shirley P. Dutton, Dennis R. Kerr, and Lee A. Jirik; assisted by Nancy J. Banta

A new 3-year research program designed to maximize recovery of natural gas from Texas reservoirs has been initiated and cooperatively funded by the Gas Research Institute, the U.S. Department of Energy, and the State of Texas. The Bureau, in partnership with the Gas Research Institute, will act

as project manager and will coordinate all studies in geology, engineering, and geophysics. The program, termed Secondary Gas Recovery, will develop and demonstrate technologies that will enable producers to better identify and produce natural gas resources that would otherwise remain unrecovered in known fields. The methodologies developed will have national applications for the improved efficiency of natural gas production.

The overall objective of the project is to further evaluate and verify a critical increment of natural gas resource in known reservoirs that has only recently been quantified. That increment, a volume of the natural gas resource amenable to improved recovery, was recently estimated in a study done by the Bureau for the U.S. Department of Energy to be about 120 trillion cubic feet (Tcf) in the lower 48. About 45 Tcf of that resource is estimated to exist in Texas. Program results will also apply to development of inferred reserves in nonassociated gas fields, which amount to 85 Tcf (lower 48), and to development of compartmentalized oil reservoirs that contain about 60 Tcf of associated gas resources (lower 48).

Unrecovered gas in known fields can be a cost-effective resource inasmuch as gas production facilities and pipeline gathering systems are already in place. Project emphasis will be placed on characterizing and evaluating the internal geometry of gas reservoirs, including the distribution of gas-bearing compartments and of barriers to gas flow. The project will be field oriented and will focus on reservoirs in two gas-producing regions of the state: sandstone reservoirs in South Texas and carbonate reservoirs either in East Texas or in the Permian Basin of West Texas.

Studies will be conducted cooperatively with operators during the drilling of field development wells as a cost-effective means of collecting data and performing interim tests of research progress. Data collection from cooperative wells will allow site selection for research wells, termed Staged Field Experiment wells, to be drilled specifically for research purposes to confirm or challenge research progress and to test state-of-the-art technologies. One Staged Field Experiment well will be drilled in each of the two major regions of study during the 3-year program.

Integrated methodologies to be demonstrated in the Secondary Gas Recovery project are aimed at better identification of untapped compartments in existing reservoirs, better identification of bypassed gas in existing wells, and improved prediction of deeper pool potential in existing fields. Initial field efforts in sandstone reservoirs of South Texas will target complex, vertically stacked fluvial-deltaic deposits in formations like the Frio, which contains some of the most productive gas fields in the United States. Results of the program will be made directly available to all natural gas producers in Texas and the nation.

Gas Saturation as a Limit on Pore-Fluid Composition and Diagenetic Alteration in Deep Sedimentary Environments

Regina M. Capuano, principal investigator

The Texas Higher Education Coordinating Board has funded a 2-year program under its Advanced Research Program to collect and analyze liquid and gas samples of fluids from kerogen-rich geopressured sediments along the Texas Gulf Coast to determine the extent of carbon dioxide and methane saturation. Although fluid composition in sandstone aquifers, diagenetic reactions of these fluids with minerals composing the sandstone, and the resulting alteration mineralogy have been studied and described by many researchers, the limits placed on fluid composition and mineral-fluid reactions by the solubility of the gases carbon dioxide and methane have not yet been considered. It has been recognized that (1) carbon dioxide and methane are released as products of kerogen decomposition during sediment diagenesis and that (2) the hydrologic conditions present in geopressured sediments favor enrichment of pore fluids in these gases in contrast to hydrologic conditions present in normally pressured sediments, which do not favor enrichment of these gases. The only effect of these gases on mineral-fluid equilibria that has been considered previously is the ability of carbon dioxide gas to acidify pore waters and thereby dissolve silicate and carbonate minerals.

To measure carbon dioxide and methane saturation, fluids will be sampled from two hydrologically distinct areas, and the compositions of the subsurface fluids will be reconstructed, taking into account the changes that occurred as a result of the fluids' being transported to the surface. The extent of carbon dioxide and methane saturation and mineral equilibria in these subsurface fluids will be determined, and alteration minerals that would precipitate from these solutions during diagenesis will be predicted through numerical simulations of mineral-fluid interactions. Information on the mechanisms of diagenetic alteration in kerogen-rich geopressured sediments and the composition of the alteration mineralogy produced allows reconstruction of the hydrologic and geochemical history of mature sediments through recognition of past occurrences of kerogen and sediment geopressuring, from kerogen-poor sediments or underpressured episodes.

Coal

North-Central Texas Bituminous Coal

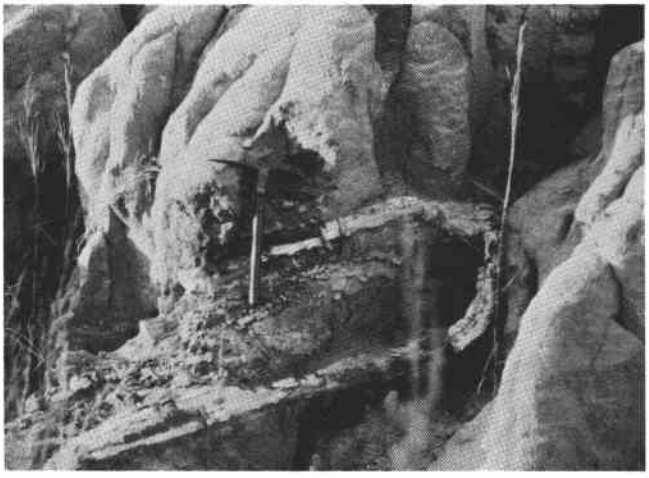
Walter B. Ayers, Jr.

Study of the depositional settings of bituminous coals in the upper Pennsylvanian and lower Permian Harpersville Formation of North-Central Texas is continuing. Cross sections were made to demonstrate regional variations in depositional systems that were previously delineated in lithofacies maps. Little Bull Creek surface mine near Rockwood, the only active coal mine in North-Central Texas, was studied in 1988 in an effort to determine the relationship between the coal seam and host strata. Because the mine temporarily ceased operations in June 1987, water has accumulated in the pit, covering the coal and thwarting this goal. However, cores stored at the mine site were examined, and coal samples were taken for analysis by U.S. Geological Survey researchers.

Computerized Calculation of Lignite Resources in Texas

William R. Kaiser, project director; Mary L. W. Jackson

This ongoing project, funded by the U.S. Geological Survey (USGS) since 1979, provides estimates of remaining near-surface lignite resources (those under less than 500 ft of cover) in Texas. The computerized data base and graphics software of the National Coal Resources Data System (NCRDS) are used to calculate resources according to criteria of USGS Circular 891. No resources were calculated in 1988, pending digitization by the USGS of point-source data for the Jackson/Yegua trend in East Texas.



Petrified log in channel-fill sandstone of the Simsboro Formation (Wilcox Group), a regional aquifer in east-central Texas. The Simsboro Formation underlies and interfingers with some Wilcox lignite seams that were evaluated for the USGS NCRDS study.

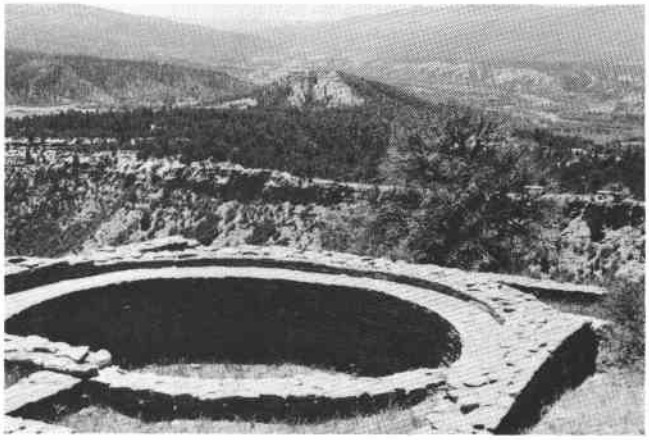
Geologic Evaluation of Critical Production Parameters for Coalbed Methane Resources

Walter B. Ayers, Jr., project director; William R. Kaiser and William A. Ambrose; assisted by Thomas E. Swartz, Sarah D. Zellers, and Monty M. Newton; in cooperation with the Geological Survey of Alabama and Colorado Geological Survey

Coal seams in the United States contain an estimated 500 Tcf of coalbed methane. The goals of this project, which is funded by the Gas Research Institute, are to determine the geologic and hydrologic factors that control the availability and producibility of coalbed methane in the San Juan and Black Warrior Basins, the major producing basins in the United States, and to develop models that will optimize production and ensure an economic supply of natural gas. The Bureau is leading research on the Fruitland Formation (Upper Cretaceous) of the San Juan Basin; the Colorado Geological Survey is subcontracted for part of the study. The Geological Survey of Alabama is subcontracted to study coalbed methane in the Pottsville Formation (Lower Pennsylvanian) of the Black Warrior Basin.

Research in the San Juan Basin, which is located in Colorado and New Mexico, focused on a regional hydrologic study of the Fruitland Formation and a local geologic study of the Fruitland Formation and the underlying Pictured Cliffs Sandstone. Hydraulic head, pressure gradient, and hydrochemistry data from the Fruitland Formation show two distinct hydrologic regions in the basin; these are an overpressured north-central San Juan Basin dominated by Na-HCO_3 formation waters and an underpressured south basin dominated by Na-Cl formation waters. The transition from overpressuring to underpressuring is marked by pronounced steepening of the potentiometric surface coincident with southwestward pinch-out of thick coals seams and upper Pictured Cliffs sandstone tongues. Fruitland overpressuring is attributed to artesian conditions; recharge is primarily at the elevated northwest margin of the basin where coal seams crop out. Within the two hydrologic regions, the chemical compositions of waters produced from Fruitland coal seams and sandstones are similar, and pressures in the two lithologies do not differ significantly, indicating hydraulic communication between sandstones and coal seams. Coalbed methane is produced from both underpressured and overpressured Fruitland strata.

The geologic study in the San Juan Basin focused on sedimentology and coal occurrence in a 200-mi^2



Outcrop of the Pictured Cliffs Sandstone (center of photo) at Chimney Rock in the northern San Juan Basin, Colorado. The Pictured Cliffs Sandstone is a coastal unit that bounds thick Fruitland coal seams on their northeast margins. The remains of an Anasazi kiva is in the foreground.

area in northern Rio Arriba and San Juan Counties, New Mexico. Fruitland coal seams (peats) are bounded on the basinward (northeast) side by Pictured Cliffs barrier-strandplain sandstones. Temporarily, migration of the Pictured Cliffs shoreline was restricted by tectonically induced subsidence along the axis of the San Juan Basin, allowing accumulation of thick coal seams landward of the shoreline; Fruitland coal occurs in as many as 14 seams that have a net thickness as great as 110 ft. Both Fruitland coal seams and the associated Pictured Cliffs shoreline sandstones are elongate to the northwest, favoring regional movement of fluids (gas and water) parallel to that trend.

Hydrologic research in 1989 will include evaluations of (1) hydrologic communication between the Pictured Cliffs Sandstone and the Fruitland Formation, (2) ground-water circulation in the Fruitland Formation, and (3) trapping mechanisms for coalbed methane. In geologic research, Bureau researchers will (1) study the regional depositional systems and coal occurrence and (2) describe outcrops and cores to calibrate geophysical logs and verify coal/framework sandstone relationships. Finally, Fruitland coalbed methane production will be related to geologic and hydrologic parameters to identify controls on coalbed methane occurrence and producibility in the San Juan Basin.

In the Black Warrior Basin of Alabama, the Geological Survey of Alabama studied the Black Creek and Mary Lee coal groups of the Pottsville Formation in the Brookwood and Oak Grove coalbed methane fields. Studies focused on hydrology; joints, cleats, and lineaments; and production.

A water-table map for the Upper Pottsville Formation in the east Black Warrior Basin generally reflects the local topography. However, dewatering at Brookwood and Oak Groves fields has locally depressed the water table. Piper (trilinear) diagrams show slightly saline to very saline Na-Cl waters in the Brookwood field and fresh to moderately saline Na-Cl-HCO_3 waters up flow in the Oak Grove field.

Northeast-oriented face cleats in the Brookwood and Oak Grove fields developed in response to regional compressive stress probably related to the Ouachita orogeny, whereas northwest-oriented face cleats and joints formed as result of the Alleghanian orogeny. Northeast-oriented joints are attributed to unloading, and they reflect the existing stress field.

Analysis of production data shows that initial potentials exceeded 200 thousand cubic feet per day (Mcfd) in 12 percent of the wells in the Brookwood field and 9 percent of the wells in the Oak Grove field. In Oak Grove field, 12 of 13 wells that produce more than 200 Mcfd occur along an individual northeast-trending lineament.

Studies of coalbed methane in the Brookwood and Oak Grove fields will be completed in 1989, and techniques developed in the field studies will be used to evaluate the occurrence and producibility of coalbed methane throughout the Black Warrior Basin.

Land, Water, and Environmental Resources Investigations

Waste Isolation Studies

Geologic Studies of West Texas Bedded Salt Deposits for Storage of High-Level Nuclear Waste

Jay A. Raney, Alan R. Dutton, and Jonathan G. Price, coprincipal investigators

Since 1977 the Bureau had been conducting studies to determine the feasibility of locating a long-term high-level waste repository in the Texas Panhandle. In December 1987, the Nuclear Policy Act Amendment directed the Secretary of Energy to cease all site-specific activities at the Deaf Smith County site within 90 days. The Bureau was required to provide the Salt Repository Project Office (SRPO) with a plan for phasing out activities related to the West Texas salt repository.

For the past 11 years the project has been funded by the U.S. Department of Energy and has provided research support for compilation of a massive data base on the Palo Duro Basin. Bureau staff have published more than 250 reports and abstracts based on their investigations related to the project. Much of the Bureau's high-level waste isolation research focused on development of predictive modeling methodologies and conceptual generic and quantitative models for application to site characterization and performance assessment. During the life of the project the Bureau has developed a unique capability and the technical resource base required for development, evaluation, and assessment of long-term predictive geological process models useful in validation of high-level waste repository integrity.

The Bureau's phaseout of the technical work related to the high-level waste isolation research was twofold. First, the status and results of selected work packages had to be documented. Second, informational data bases and other technical data files for appropriate work packages had to be compiled, inventoried, and preserved in a form that would facilitate their transfer to the Office of Civilian Radioactive Waste Management (OCRWM). Records turnover also included data files and supporting documentation not previously tied to specific contract reports or related to the past 300 man-years of professional staff time spent during the project.

Quality assurance (QA) requirements controlling records turnover and preservation were met. All maps, cross sections, and other illustrative materials had to be both legible and reproducible. Many of the materials related to current work packages had to be revised to fit this requirement. The Bureau's QA staff was responsible for adherence to records management procedures. The QA staff was also responsible for maintaining the Records Center and was required to coordinate all records turnover activities as well as monitor and verify reprocessing of all core material and other samples.

The Bureau now curates more than 110,000 ft of SRPO core in its Core Research Center (CRC). Besides core from the West Texas project, salt cores from Louisiana, Mississippi, and Utah are also curated at the CRC in the SRPO collection. The core curation work is scheduled to continue.

To conclude field activities certain reclamation work was required. The Bureau removed weather monitoring stations, erosion monitoring sites, and soil process sites. These sites were restored to their original condition and all field-related activities were completed in August 1988.

Evaluation of a Proposed Texas Site for Repository of Low-Level Radioactive Wastes

Jay A. Raney, program director; Charles W. Kreitler, coordinator of hydrologic studies; M. Saleem Akhter, Robert W. Baumgardner, Jr., Regina M. Capuano, Edward W. Collins, Carolyn E. Condon, Alan R. Dutton, R. Stephen Fisher, Thomas C. Gustavson, Rodney I. Heathcott, Christopher D. Henry, William F. Mullican III, Bernd C. Richter, Jeffrey N. Rubin, Bridget R. Scanlon, and Rainer K. Senger; assisted by James A. Doss, Daniel H. Ortuño, Alex Justman, Joong H. Kim, and Fred P. Wang

The Bureau's involvement with the State of Texas program to find and evaluate a proposed site for a low-level radioactive waste repository began in 1986. At that time the Bureau was asked by the Texas Low-Level Radioactive Waste Disposal Authority to conduct preliminary investigations of potential sites identified by the Authority in three areas in Culberson and Hudspeth Counties in Trans-Pecos Texas. Partly on the basis of that work the Authority selected a site in southern Hudspeth County about 10 mi northeast of Fort Hancock for further investigations.

Studies of the site near Fort Hancock are unique in the national low-level radioactive waste disposal

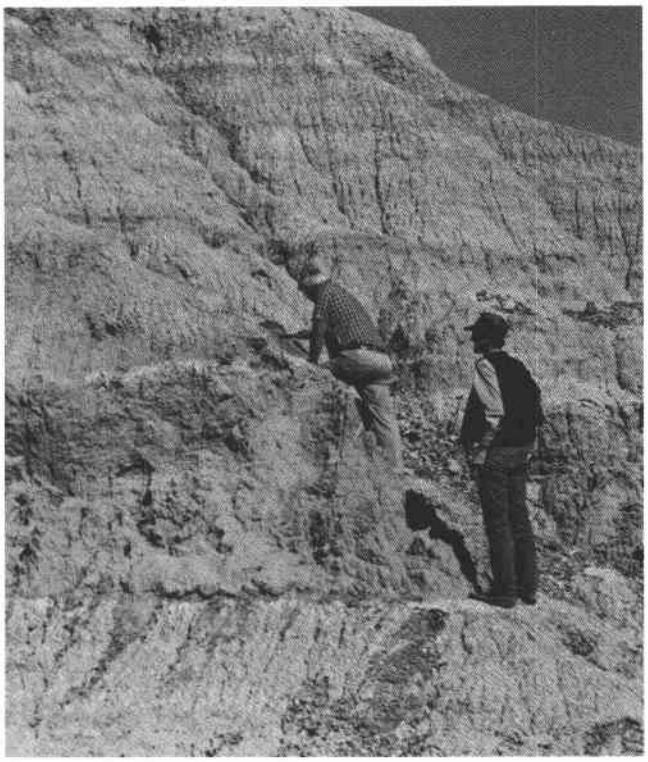
program in that most of the technical evaluations are being undertaken by researchers associated with State universities. The role of the Bureau is to conduct geologic and hydrologic investigations and to coordinate geotechnical work by the Departments of Civil Engineering at The University of Texas at Austin and at El Paso and geophysical studies by the Department of Geological Sciences at The University of Texas at El Paso.

The geological studies include stratigraphic, structural, and geomorphic investigations as well as compilations of regional data on the geology and resources of the site vicinity. The main emphasis of the stratigraphic studies is the evaluation of the thick sequence of upper Cenozoic basin-fill sediments in the Hueco Bolson that are the host strata of the proposed repository. In addition to descriptions of outcrops in the region near the site, boreholes have been drilled to obtain samples from the site. These materials are being analyzed by the Bureau's Mineral Studies Laboratory to determine mineralogy and grain size. The depositional framework for this portion of the Hueco Bolson will be synthesized so that the site stratigraphy may be placed in its regional context. Stratigraphic studies are important both for engineering analysis and design of the repository and for understanding the hydrology of the site.

Structural studies are concentrated on a system of Quaternary and older normal faults, the Campo Grande fault system, that lies about 5 mi south of the proposed site. Strands of this fault system clearly displace "old" Quaternary deposits and geomorphic surfaces and are overlain by undisturbed younger Quaternary deposits and terraces. Absolute dates of fault activity have not yet been determined. Excavations across the faults are planned that will clarify fault geometries and may allow materials to be obtained for absolute dating. Understanding the Cenozoic faulting history is an important part of the analysis of seismic risk. Fractures in the Mesozoic bedrock exposed in the vicinity of the site will also be studied.

Geomorphic studies, including erosion and recent sedimentation, are essential to understanding the effects of the flow of surface waters across the site and to determining the long-term (300- to 500-yr) integrity of the proposed facility. These efforts are closely integrated with hydrologic studies of surface water and also overlap with the geomorphic study of the Quaternary faulting and with the genetic and descriptive stratigraphic investigations. Erosion pin fields and rain gauges have been installed as part of the monitoring activities near the site.

Hydrologic studies are critical to the evaluation of the site because water is a medium for transport of radionuclides from the repository to the accessible environment. These studies include investigations of the surface waters, the unsaturated zone, and the saturated zone. Activities include monitoring and evaluation of the current hydrologic environment and extensive computer modeling both to describe and to predict the surface and subsurface behavior of ground waters at and near the site. Much of the analytical work is being conducted by the Bureau's Mineral Studies Laboratory.



Bureau researchers Thomas C. Gustavson (left) and Edward W. Collins examine outcrops of clastic sediments in the Hueco Bolson, West Texas.

Surface water studies will rely extensively on computer models. These are supported by (1) analysis of the morphology of the drainage basins near the site, (2) determination of longitudinal and cross-channel profiles, and (3) analysis of data from three stream gauging stations on the site, a still well installed in a tank near the site, five rain gauges near the site, and regional historical records.

Studies of the unsaturated zone involve the investigation of ground water in the top 500 ft of strata in the site vicinity. Water content, water chemistry, pressure distributions, recharge mechanisms, and rates of ground-water flow are among the topics to be investigated. A variety of field monitoring procedures and laboratory analytical techniques are being used to evaluate the ground-water system in the vadose zone and to provide data for computer modeling.

The deep saturated zone is being investigated using existing wells in the region around the site and data acquired from two wells drilled to the water table on the site. In addition to pump tests and the determination of the regional potentiometric surface, geochemistry is being used extensively to determine both the age and the chemistry of the waters present near the site. Many of the wells are monitored every 3 months to establish a baseline of geochemical data.

The data and interpretations will be reported to the Authority by September 1989. The report will include not only information gathered at and near the site but also regional information compiled from the work of other researchers so that the site may be described in its regional geologic and hydrologic setting. The Authority will use this information to determine if this is a favorable site for a low-level radioactive waste repository, if additional data are needed to select a site, or if data are adequate for license application.

Texas Nuclear Waste Program

L. F. Brown, Jr., project director; Alan R. Dutton, principal investigator; Jules R. DuBar, Thomas C. Gustavson, and Stephen C. Ruppel

In 1985 the U.S. Department of Energy (DOE) selected a 9-mi^2 area in Deaf Smith County in the Texas Panhandle for site characterization to test the feasibility of the area as a repository for high-level nuclear waste. The Texas Nuclear Waste Program, funded by an interagency grant from the Texas Governor's Office and approved by DOE, had two tasks: to monitor the site investigations and to review technical documents for the Governor's Office. In December 1987, the U.S. Congress directed DOE to focus repository-siting studies solely on Yucca Mountain in Nevada. This eliminated the need for monitoring the investigations in Deaf Smith County. During 1988 the principal task of the Texas Nuclear Waste Program was to summarize the results of geologic and geohydrologic studies of the Palo Duro Basin in the Texas Panhandle. Knowledge of the geology and hydrogeology of the large and complex Palo Duro Basin was minimal in 1977, when DOE began their regional investigations, in large part because of the previously limited success of hydrocarbon exploration in the basin. The ensuing decade of research produced significant new knowledge of stratigraphy, regional tectonics, geomorphology, hydrocarbon potential, geochemistry, hydrogeologic properties, and ground-water flow in the basin. The final report of the Texas Nuclear Waste Program is a comprehensive synthesis of this knowledge. The report also identifies the perceived scientific issues that remain to be addressed and answered before a high-level nuclear waste repository could be sited in the Texas Panhandle in any future program.

Hydrologic-Hydrochemical Characterization of Texas Gulf Coast Saline Formations Used for Deep-Well Injection of Chemical Wastes

Charles W. Kreitler and M. Saleem Akhter; assisted by Andrew C. A. Donnelly

A hydrologic and hydrochemical study of the Tertiary saline formations in the Texas Gulf Coast was completed in 1988. This 2-year program, funded by the U.S. Environmental Protection Agency, investigated the hydrologic environment and the fluid-migration potential in the saline strata used for deep-well injection of chemical wastes. Efforts of the first year concentrated on acquiring and evaluating bottom-hole-pressure data from oil- and gas-bearing formations. Pressure-depth plots and potentiometric-surface maps were constructed to identify various pressure regimes and regional fluid-flow trends in the Frio Formation, a principal hydrocarbon producer and a principal repository for chemical waste. Widespread depressurization, identified in the productive formations, can be linked to extensive hydrocarbon production over the years. Residual potentiometric surfaces of discrete depth intervals were used to investigate local trends and cross-formation flow potential. Work of the second year included preparation of county-scale potentiometric maps to better detail the depressurization. Mapping in Victoria County showed a coincidence of depressurized regions with hydrocarbon-producing zones. This technique is useful for siting and monitoring of injection facilities.

Water chemistry data from field sampling of 32 oil fields were integrated with similar data from published sources to better understand the hydrologic environment. The principal findings of this investigation indicate that (1) active recharge of the Frio by continental waters is not occurring, (2) water chemistry in the northern Gulf Coast is controlled by salt-dome dissolution, and (3) brines from the deeper geopressured section may be leaking into the hydrostatic section of the central and southern Gulf Coast Frio. Analyses of oil-field brines also indicate evidence of microbial degradation, which has important implications for degradation of injected chemical wastes.

Geochemical Reactions between Injected Chemical Wastes and Host Rock

Regina M. Capuano and Charles W. Kreitler; assisted by Andrew C. A. Donnelly

This 1-year project to study the deep-subsurface degradation of hazardous wastes disposed of by deep-well injection was funded by the Office of Drinking Water, U.S. Environmental Protection Agency. Before this project began, little was known of the chemical composition of waste streams disposed of by deep-well injection and of the chemical reactions that limit the mobility of hazardous compounds in these generally multicomponent waste streams. The compositions of the waste streams injected into all of the 98 active noncommercial Class I injection wells in Texas were compiled from the Underground Injection Control files of the Texas Water Commission. These Texas waste streams represent 60 percent of the 8.5 billion gallons of industrial waste disposed of annually in the United States by deep-well injection.

Most of the Texas waste streams (80 volume percent) were found to contain organic compounds derived from chemical manufacturing. The more significant hazardous compounds injected annually are phenols, chlorinated organics, nitriles, ketone-aldehydes, and cyanide. Anaerobic reactions are the favored method of subsurface degradation for all these chemical groups except cyanide. Microbial degradation at the depths of deep-well injection has recently been suggested by other work at the Bureau. Hydrolysis and chemical interactions are considered next in importance, followed by the potential for sorption to immobilize hazardous compounds. Nonhazardous organic compounds, such as carboxylic acids and alcohols, which are disposed of in most hazardous waste streams, may strongly influence the progress and styles of hazardous-compound transformations. Within the deep subsurface aquifers commonly used for disposal, the types and rates of degradation activities are expected to vary spatially and temporally and are dependent upon shifts in solution pH, oxidation potential, temperature, and the ability of microbial populations to acclimate to these changing conditions with distance from the wellbore.

Much additional work is needed to predict accurately hazardous compound degradation in multicomponent waste streams under deep aquifer conditions. This work should include both thermochemical calculations and field testing, particularly testing for evidence of microbial activity and degradation.

Ground-Water Studies

Geologic and Hydrologic Investigations, Reese Air Force Base, Lubbock, Texas

Charles W. Kreitler, principal investigator; Rainer K. Senger, and Thomas C. Gustavson

The U.S. Air Force Training Command asked the Bureau to evaluate the distribution of geologic facies and the hydrology of the Blackwater Draw and Ogallala Formations at Reese Air Force Base, Lubbock, Texas, to determine whether there were geologic or hydrologic controls on the distribution of organic contaminants in the ground water beneath the base.

Examination of core material identified two predominant depositional facies—eolian sands and fluvial gravels. The upper gravels appear continuous across the air base and may represent the major water-bearing unit, and therefore, the prime conduit for contaminant migration beneath the base. Continuous water level recorder data from water supply wells and monitoring wells on the base showed confined and unconfined conditions. Confinement may be controlled by the wells' proximity to the playa lakes on the air base or by the relationship of water levels in the wells to the elevation of the water-bearing gravel unit. This variability in the degree of confinement indicates a more complex hydrologic setting than is normally recognized for the Ogallala aquifer.

Impact of Surface- and Ground-Water Management Strategies on Ground-Water Resources of the Gulf Coast Aquifer in Wharton and Matagorda Counties

Charles W. Kreitler, program director; Alan R. Dutton, principal investigator; Bernd C. Richter; assisted by John L. Garber and John E. Nicol

Careful management of water resources in the Colorado River Basin in the Texas Coastal Zone is required as the population in the region increases and as greater demands are placed on available water. The Lower Colorado River Authority is funding a program at the Bureau to study water resource management strategies applicable in Wharton and Matagorda Counties. Additional water can be obtained from two different sources: (1) water artificially recharged when additional flow is available from the Colorado River and (2) natural ground water that is already available in the Gulf Coast aquifer within the drainage basin. Conjunctive

use of surface and ground water, with water pumped from aquifers to meet peak resource demand, is an established resource management strategy.

This study is designed to (1) determine the impacts of artificial recharge and conjunctive surface- and ground-water use on the ground-water budget of the Gulf Coast aquifer in Wharton and Matagorda Counties, and (2) develop procedures for detailed evaluation of impacts from alternative water management strategies. The approach uses a numerical computer model to represent the local ground-water flow system. Model simulations will be analyzed to predict the effects of recharge ponds and deep injection wells on the ground-water budget, to compare the amount of ground water required by conjunctive use with the volume of natural ground-water flow near the Colorado River, and to determine how other ground-water users would be affected by the various water management strategies.

Work tasks for the first half of the contract period included collection and interpretation of hydrologic and geologic data that form the basis of the model, model calibration, and preliminary simulations. Subsurface geologic information from approximately 600 geophysical and water-well driller's logs were entered into a computerized data base for flexible, efficient, and rapid construction of maps of the subsurface distribution of sand packages in the Gulf Coast aquifer. Nine stratigraphic cross sections across Wharton and Matagorda Counties and parts of adjacent counties, including dip and strike sections, were completed. Stratigraphic interpretation was based on results of previous studies in the area. Potentiometric surface maps were constructed to show possible directions of ground-water flow, to establish hydrologic boundary conditions in the model, and to support model calibration. Hydrochemical facies were mapped to help interpret the ground-water flow pattern necessary for building the conceptual model of the flow system. The modeling procedure consists of locating model boundaries, constructing the model framework, assigning boundary conditions and hydraulic conductivity values, and simulating various scenarios of flow conditions to calibrate the model and to study possible impacts.

Developing Guidelines for Wellhead Protection Areas in Confined Aquifer Settings

Charles W. Kreitler, principal investigator; Rainer K. Senger

Much of the ground water of the United States is produced from confined aquifers. Because of their confinement the threat of contamination to wells in these aquifers is lessened, though still present, in comparison with water table (unconfined) aquifers. However, all public water supply wells, whether in confined or water table aquifers, need wellhead protection programs. Wellhead protection programs for wells in unconfined aquifers can be established through techniques such as calculated or arbitrary fixed radius, simplified variable shapes, analytical solutions, and numerical models that have already been developed. These techniques assume that recharge occurs uniformly around the well. The protection of confined aquifers requires different approaches. The zone of major recharge to a confined aquifer may be far away from the producing well. Hydrologic and geologic discontinuities, however, may permit localized leakage of water and contaminants into a producing zone. Such discontinuities may include fractures or abandoned wells and inappropriate sealing of well casings.

The Bureau is developing the methodology for the Office of Ground Water Protection, U.S. Environmental Protection Agency, for delineating wellhead protection areas for wells in confined aquifers. Delineation will be a two-step process. The first step involves defining the nature of confinement, which can be accomplished through geologic, hydrologic (pump testing, interpretation of elevation of the potentiometric surface and continuous water-level data, numerical modeling), and geochemical (interpretation of absolute age measurements with radioactive isotopes) approaches. In the second step the type of protection area needed is specified once the potential zones for leakage have been determined and the criteria for wellhead protection, such as zone of influence, zone of contribution, and time of transport, have been established. The results will be presented in a technical manual for State water agencies to use in defining wellhead protection areas for their states.

A Pilot Geographic Information System for the Edwards Aquifer Recharge Zone

E. G. Wermund, principal investigator

The objectives of this study are to test the new Geographic Information System (GIS) technology for solving a geohydrology problem and to express in quantitative terms the sensitivity of different areas of the Edwards limestone aquifer recharge zone to natural and human impacts.

A GIS, a technique to simultaneously search and integrate information from differently formatted data bases, has become an increasingly common

tool for governmental decisionmaking. The GIS allows a manager to link spatial data bases with more common data bases. The spatial data generally appear in map or graphic formats, whereas other data, usually called attributes, occur in data bases with tabular or textual formats. Sophisticated software allows simultaneous searches of both data bases and provides responses in a map, graphic, tabular, or textual format.

A 15-mi^2 area near Helotes, Bexar County, was selected as the test area because that location encompasses a sensitive recharge area where urban development is expanding as a part of San Antonio's growth. In 1988, most spatial data were digitized from the U.S. Geological Survey topographic quadrangle map and Bureau maps. Completed map layers include roads and buildings, streams, slopes, areal geology, environmental geology, and fractures. Slope classes of less than 2°, 2–5°, 5–15°, and more than 15° may be examined separately. Three fracture maps may also be displayed separately: number of fractures, length of fractures, and number of fracture intersections per unit area. An up-to-date land use map remains to be interpreted and digitized.

The attribute data have been selected, but the formatting and input of the tabular and textual data bases are still under way. These data include stream gauge measurements and flood levels, precipitation amounts, water well production, water levels, water chemistry, waste systems, point and nonpoint source pollution, and census results. Software to interrelate spatial and attribute data will be selected and tested in 1989.

Coastal Studies

State Submerged Lands of Texas—Sediments, Geochemistry, Benthic Macroinvertebrates, and Associated Wetlands

William A. White, Thomas R. Calnan, Robert A. Morton, and H. Seay Nance; David W. Koppenaal and Steven W. Tweedy, chemists; Barbara M. Hartmann and Tony M. Walston, cartographers

Work on this comprehensive inventory of Texas coastal submerged lands and associated wetlands continued in 1988. Previous funding has been provided by the Minerals Management Service, U.S. Department of the Interior, and the General Land Office and Governor's Budget and Planning Office of the State of Texas with grants administered by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

This multiphase project is based on textural, geochemical, and benthic macroinvertebrate analyses of selected sediment samples that were collected on 1-mi centers from the inner continental shelf and from the bay-estuary-lagoon systems. Coastal wetlands were mapped and described using color-infrared photographs and field surveys. A major objective of the study is to produce an extensive data base characterizing submerged lands and wetlands along the entire Texas coast from Sabine Lake to the Rio Grande.

The submerged lands atlas of the Bay City-Freeport area was published in 1988. This atlas is the fifth in a series of seven that will cover the entire Texas coast. Other published atlases cover the Corpus Christi, Galveston-Houston, Brownsville-Harlingen, and Beaumont-Port Arthur areas. Editing of the Port Lavaca text was completed in 1988. The Kingsville text was submitted to peer review during the year. Both of these atlases will be published in 1989 and will complete the study.

Atlases consist of a text and a series of 17 maps including (1) 4 maps (scale 1:250,000) depicting the distribution of sediment textures, (2) 12 maps (scale 1:250,000) depicting concentrations and distributions of selected trace, minor, and major elements in sediments, and (3) 1 full-color map (scale 1:125,000) depicting the distribution of coastal wetlands and associated environments as well as the distribution of benthic macroinvertebrate assemblages and species diversity in submerged lands. By the end of 1988, textural and geochemical maps of the Port Lavaca area were cartographically completed, and much progress had been made on maps of the Kingsville area.

In the study of sediment texture and geochemistry, the use of standardized analytical methods for different areas of the coast has allowed a comparison of parameters such as textural properties and trace-metal concentrations from one bay or shelf area to another. In addition, normalization of elemental concentrations using percent mud has proved to be an effective method for characterizing and defining bay and shelf sediment trace-metal content.

Benthic macroinvertebrates found in bay-estuary-lagoon and inner shelf sediments are primarily polychaetes, bivalves, gastropods, and crustaceans. On the inner shelf, stations having higher percentages of sand generally have more benthic species. Diversity on the inner shelf is generally high to very high. Cluster analysis was used to delineate benthic communities in all bays and on the inner shelf.

Delineation of coastal wetlands and associated environments continued in 1988. One objective of the study is to produce updated regional full-color maps of wetlands; units are patterned after the

Bureau's *Environmental Geologic Atlas of the Texas Coastal Zone* series. Wetland maps of the Port Lavaca and Kingsville areas are in various stages of hand-coloring, editing, and cartographic preparation. The first color proof of the wetlands map of the Port Lavaca area was completed during 1988.

Fluvial-Deltaic Marsh and Estuarine Sedimentation, Texas Gulf Coast

William A. White and Thomas R. Calnan, principal investigators; Thomas L. Pinkston and Steven W. Tweedy

Funded through an interagency cooperation agreement with the Texas Parks and Wildlife Department, this project includes both a literature synthesis and field investigation, which address fluvial-deltaic marsh and estuarine sedimentation as well as associated interactive processes.

Published and unpublished data were reviewed and analyzed to determine the present and historical role of fluvial sediments in developing and maintaining habitats in estuarine and marine areas along the Texas coast. Emphasis was placed on wetlands, marine grassflats, and benthic communities. Interactive processes that were analyzed include riverine discharge and associated sediment loads, subsidence and relative sea-level rise, deltaic and estuarine sedimentation rates, marsh aggradation rates, biodeposition, and human activities. A contract report, titled "Fluvial-Estuarine Sedimentation, Texas Gulf Coast: Literature Synthesis," was completed and submitted to the Texas Parks and Wildlife Department in September.

In the field investigation, salt-water marshes on the Colorado River delta and brackish-water marshes on the Trinity River delta were monitored for as long as 13 months to document sediment accumulation rates. Information on vegetation types, vegetation heights, elevations, and sediment composition was also collected during periodic surveys. Marsh aggradation rates were determined primarily by using artificial-marker horizons established at selected sites along marsh transects. Eleven markers were placed in wetlands in the Trinity River delta study area, and nine in the Colorado River delta study area.

Marsh aggradation rates on the Colorado River delta, with the exception of levee sites, are similar to those in salt marshes reported for other areas of the Gulf Coast. The highest rates (8 to more than 10 mm/yr) in the Colorado River delta occurred in *Spartina alterniflora* marshes. The location of these marshes in the intertidal zone contributed to the higher aggradation rate by increasing the frequency of inundations and the period of time during which deposition could occur. The insignificant sediment deposition on higher levee marshes is explained by the fact that no flood events with a magnitude sufficient to inundate these marshes occurred during the monitoring period. Rates of marsh aggradation on the Trinity River delta were more variable and less predictable than those on the Colorado River delta. Thicknesses of sediment that accumulated above marker horizons during a 7.5-month period ranged from 2.8 to 0 cm. Deposition and erosion patterns in the Trinity River delta indicated a seasonal variation. Some marker horizons located away from estuarine waters and near fluvial channels recorded no measurable inorganic-sediment deposition but did record patchy deposition of organic material. A contract report, "Marsh Sedimentation, Colorado and Trinity River Deltas, Texas Gulf Coast: Field Studies," was completed and submitted to the Texas Parks and Wildlife Department in September.

Continuation of the field studies in 1989 should provide additional data on marsh aggradation rates and possibly the depositional or erosional effects of a flood event. Included in these studies will be the determination of marsh aggradation rates through radiochemical dating, the documentation of changes in marsh distribution in fluvial-deltaic areas using historical monitoring techniques, and the investigation of changes in the distribution of submerged vascular vegetation within the Galveston Bay system and relationships to concomitant changes in geological and hydrological parameters. This last investigation will be a cooperative study with Dr. Warren Pulich of the Texas Parks and Wildlife Department.

Shoreline and Vegetation-Line Changes along the Texas Coast

Jeffrey G. Paine and Robert A. Morton

Texas coastal lands are increasingly used for residential construction, recreation, resource exploitation, and industrial development. This heavy usage, combined with unique hazards posed by storms, sea-level rise, and subsidence, creates the need for monitoring change of coastal boundaries. During 1988, monitoring efforts were focused on short-term changes in the Gulf shoreline and vegetation line.

In contrast to generally low rates of change along bay shorelines, Texas Gulf shorelines can change rapidly. Higher rates of movement along Gulf shorelines are caused by greater tide range, higher wave activity, more severe storm processes, and the presence of more unconsolidated sediment than occurs along most bay shorelines. Many significant

changes have occurred since studies of long-term shoreline and vegetation-line changes along Gulf beaches were published between 1974 and 1977. To update these reports, Gulf shoreline changes between 1974 and 1982 were documented at more than 300 sites between Sabine Pass and the Rio Grande. During this period, which was characterized by relatively stable sea level, lower-than-average storm frequency, average streamflow, and average rainfall, shorelines and vegetation lines were predominantly recessional. There was a net land loss of about 330 acres and a net loss of beach vegetation of about 2,000 acres between 1974 and 1982. Results of this study are scheduled to be published in 1989.

Preliminary Assessment of Economic Potential of Mineral Resources in the Outer Shelf Exclusive Economic Zone of the Gulf of Mexico

Robert A. Morton, project director; Jeffrey G. Paine

Anticipated decline in oil and gas discoveries in the Gulf of Mexico has prompted the Minerals Management Service, U.S. Department of the Interior, to identify and locate nonfuel mineral resources that would stimulate future leasing within the Exclusive Economic Zone (EEZ). Nonfuel resources of the Texas Outer Continental Shelf identified as having economic potential include sand, gravel, and some heavy minerals. Locations, composition, approximate volumes, and quality of these deposits are currently being investigated using descriptions of short gravity cores and soil borings as well as interpretations of high-resolution seismic surveys.

By yearend more than 450 foundation borings and several thousand line miles of high-resolution seismic profiles had been obtained from both public and private sources. Lithologic descriptions from the foundation borings were used to map the general distribution of shallow sand bodies on the continental shelf that might be suitable for further investigation. A report prepared at the end of the first year of investigation summarizes the suitability of the available data base for resource evaluation, selects preliminary sites for more detailed field investigations, identifies potential markets for beach quality sand, and recommends additional work.

Monitoring the Beach and Vegetation Line on Galveston Island

Robert A. Morton, project director; Jeffrey G. Paine

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 landward retreat of natural vegetation. The purpose of this study, supported by the Office of the Texas Attorney General, 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 the influence of human activities on recovery processes. This information should prove useful to owners of coastal property that is subject to storm damage and to 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. Results of the field work more than 5 years after Hurricane Alicia show that dunes are reforming in undeveloped areas but not in developed areas; furthermore, the backbeach is still lower than before the storm.

Long-period waves and abnormally high water levels generated by Hurricane Gilbert flooded West Beach during two tidal cycles on September 14 and 15, 1988. In undeveloped areas sand eroded from the forebeach was transported landward and deposited along the backbeach where post-Alicia dunes had formed. This deposition of sand raised the backbeach elevation about 1 ft. However, in developed areas the storm destroyed artificial dune ridges, eroded landfill beneath houses, and exposed concrete rubble and wooden posts that had been buried by beach recovery processes after Hurricane Alicia. The sand eroded by Gilbert from developed segments of West Beach was deposited on lawns and in streets between houses, resulting in a net loss of sand in terms of beach volume. Photographic flights and ground observations before and after Gilbert indicated that the effects of the storm were relatively minor along most of the Texas coast except in developed areas where the beach underwent additional erosion.

Mineral Resources Investigations

Igneous Petrogenesis and Ore Deposition

Jonathan G. Price, principal investigator; Christopher D. Henry, Jeffrey N. Rubin, David W. Koppenaal, Steven W. Tweedy, and Thomas L. Pinkston

Magma generation and evolution are parts of the development of certain types of ore deposits, including deposits of beryllium, fluorine, and molybdenum found in the Trans-Pecos region. Heat supplied by igneous intrusions may be essential for the formation of other types of deposits, such as certain large silver and mercury orebodies in Texas. Fundamental petrologic questions about the origin of Trans-Pecos igneous rocks and their relationships to ore deposits are being answered by field mapping, geochemical analyses of rocks and minerals, detailed petrography, potassium-argon dating, computer modeling of magmatic processes, and thermodynamic calculations.

Chemically and mineralogically unusual rhyolite intrusions near Sierra Blanca are being studied in detail, with cooperation from Cyprus Beryllium Corporation and funding from the Texas Mining and Mineral Resources Research Institute. These laccolithic intrusions are heavily enriched in beryllium and fluorine and are the ultimate sources of these elements in high-grade beryllium deposits in fluoritized limestones along the contacts with the intrusions. The Round Top intrusion appears to be the most highly enriched of the laccoliths. Its broadly homogeneous trace-element content makes it a low-grade, bulk-tonnage resource for several strategic and critical elements, including rare earth elements (especially the heavy rare earths), yttrium, zirconium, niobium, tantalum, tin, and thorium. Recent developments in new materials for high-temperature superconductors may drastically increase the demand for some of these elements. In addition to investigating the resource potential of the Round Top rhyolite, this study is also providing detailed mineralogical, petrographic, and geochemical data on the origin of the beryllium deposits in replaced Cretaceous limestones. Structure-related mineralogical features include the presence of grossular garnet in steeply dipping, skarn-type ore next to rhyolite, and the abundance of behoite, beryllium hydroxide, in gently dipping mineralized pods below the floor of the laccolith.

Chemical, petrographic, and structural data on igneous rocks and associated ore deposits in the Christmas Mountains area reveal some similarities to the Sierra Blanca area. More than 70,000 tons of metallurgical-grade fluorspar were mined from limestone-replacement orebodies on the margins of a rhyolite laccolith in the Christmas Mountains. Although locally anomalous in beryllium, the deposits do not appear to be consistently enriched, and no attempts have been made to extract beryllium. In contrast to the aluminous rhyolites at Sierra Blanca, the Christmas Mountains rhyolites are peralkaline and may have developed through different processes of differentiation and/or crustal melting.

Regional Tectonic Stress with Time and Relation to Ore Deposits

Christopher D. Henry and Jonathan G. Price

Many hydrothermal ore deposits occur as veins or were formed by fluids moving along fractures into favorable strata. Because tectonic forces affect the orientation and dilation of fractures, studies of regional tectonic stresses as a function of time aid in understanding the origin of these types of ore deposits.

An evaluation of sizes, orientations, and ages of epithermal gold-silver veins in the western United States and northern Mexico indicated a dominance in terms of numbers of veins and size of deposits during periods of crustal extension, mostly from 30 to 10 million years ago. Whereas compression-related epithermal veins older than 30 million years tend to have mostly east-northeast strikes, parallel to the direction of compression throughout the southwestern United States and northern Mexico, younger, extension-related veins tend to exhibit orientations that are not necessarily perpendicular to regional extension.

Potassium-argon dating and detailed mapping in Trans-Pecos Texas and in the Sierra Madre Occidental of Mexico helped to constrain the timing of crustal extension. Similar magmatic and tectonic histories appear to apply to both regions, which are on the eastern and western fringes of the Basin and Range physiographic province. Studies of these outlying areas are critical to understanding the Tertiary tectonic history of North America.

Texas Portland Cement Industry and Cement Resources

Mary W. McBride, Tom S. Patty (consultant, Erlin, Hime Associates, Austin, Texas), and Roger D. Sharpe (United States Gypsum Co., Chicago, Illinois)

Edwards Limestone (Lower Cretaceous) quarry in Balcones Fault Zone area. The Edwards is an important calcareous resource for Texas cement plants.

Texas was the second leading cement-producing state in the nation in 1987. A manuscript describing the industry in Texas and delineating geologic occurrence of current and potential resources, funded in part by the Texas Mining and Mineral Resources Research Institute, is in review for a Bureau publication.

The report is designed both to give the professional in the cement industry an appreciation of the vast supply of cement raw materials available in Texas and to acquaint the lay reader with an industry that produced products valued at approximately $320 million in 1987.

Industrial Minerals in Texas

L. Edwin Garner

The Texas Dimension Stone Industry and the Texas Aggregate Industry projects, both funded by the Texas Mining and Mineral Resources Research Institute, were conducted to provide characterizations of these resources and their economics. These industries make a significant contribution to the Texas economy and will have a significant effect on future urban development.

The Texas Dimension Stone Industry project addresses the growth pattern of both limestone and granite dimension stone production in Texas and the relation of Texas production to United States production and imports. An integral part of the project is to detail the distribution and characteristics of suitable dimension stone resources within the state.

The Texas Aggregate Industry project focuses primarily on the inventory and chemical and physical characterization of available crushed stone and sand and gravel resources in the state. Because growth in the aggregate industry is tied to construction and general economic development, particular emphasis is placed on the proximity of suitable reserves to metropolitan areas. This study also addresses the growth pattern of aggregate materials as related to population trends and urban development.

Texas Mining and Mineral Resources Research Institute

Jonathan G. Price, director

The Texas Mining and Mineral Resources Research Institute (TMMRRI) is one of 32 state organizations partly funded and administered by the U.S. Bureau of Mines and dedicated to research and academic training in mineral resources and technology. The Bureau of Economic Geology administers TMMRRI. The University of Texas at Austin, Texas A&M University, and Prairie View A&M College, a subdivision of Texas A&M, are academic affiliates of TMMRRI. Funds from the Bureau of Mines are matched at least two-to-one from non-Federal sources.

TMMRRI supports training and education of mining and mineral resource personnel through graduate fellowships, research assistantships, and undergraduate scholarships. The advisory board for TMMRRI is composed of the President of The University of Texas at Austin, the Vice-Chancellor and Dean of Engineering at Texas A&M University, and a member of the Railroad Commission of Texas. Representatives of the advisory board plus two members of the Texas mining industry serve on the TMMRRI Fellowship Committee. For the 1988-89 academic year three fellowships were awarded to support graduate research in geotechnical aspects of rock mechanics and petroleum recovery. In addition, three graduate students received support in 1988 through research assistantships on TMMRRI-funded mineral resources projects. These students are given the opportunity to participate in organized research that is often broader in scope than that for a dissertation or thesis.

TMMRRI-supported research projects include hard-mineral resource studies of igneous petrogenesis and related geologic mapping, regional tectonic stresses, sulfur, cement, and other industrial minerals, and energy resource studies of lignite and coalbed methane.

Mapping Investigations

Geologic Atlas of Texas

Virgil E. Barnes, project director

Revision of out-of-print maps continued in 1988. The Beaumont, Sherman, and Abilene Sheets are in cartographic preparation. The Palestine (out of print) and the Tyler and Waco Sheets (estimated to go out of print in 1990) have been revised and are ready for processing.

Geologic Map of Texas

Virgil E. Barnes, project director; Dan F. Scranton, cartographer

A new 1:500,000-scale geologic map of Texas is being prepared to replace the U.S. Geological Survey's "Geologic Map of Texas," which was published in 1937 and has been out of print for many years. The new map, which will be printed in quadrants, is ready for color separation. The major change from the earlier map is much more detail (a total of approximately 350 units) in the new map.

Tectonic Map of Texas

Thomas E. Ewing (consultant, San Antonio, Texas), Martin P. A. Jackson, Christopher D. Henry, Roy T. Budnik (consultant, Poughkeepsie, New York), Stephen C. Ruppel, Charles M. Woodruff, Jr., (consultant, Austin, Texas), William R. Muehlberger (The University of Texas at Austin, Department of Geological Sciences), James R. Garrison (consultant, Arlington, Texas), Richard L. Nicholas (Shell Oil Company, Houston, Texas), and Arthur G. Goldstein (Colgate University, Department of Geology); John T. Ames, cartographer

This project will produce a full-color 1:750,000-scale map of Texas. The map incorporates extensive surface and subsurface data from Texas and adjoining states. Lithotectonic units are shown in areas of basement exposures, such as the Llano region in Central Texas and the Van Horn area of Trans-Pecos Texas. The structure of selected subsurface stratigraphic horizons is shown between the basement exposures. Contours and faults illustrate the structural complexity of major oil- and gas-producing sedimentary basins in the state. Small-scale inset maps show statewide gravity and magnetic data and lithologic and isotopic age data on basement terranes. The map will be printed in quadrants; color separation is complete on the southwest quadrant.

Geologic Mapping of the Christmas Mountains and Hen Egg Mountain 7.5-Minute Quadrangles, Trans-Pecos Texas

Christopher D. Henry, Jonathan G. Price, and Donald E. Miser; David M. Ridner, cartographer

Geologic mapping of these two quadrangles north of the Terlingua mercury district and Big Bend National Park, funded in part by the U.S. Geological Survey's Cooperative Geologic Mapping Program (COGEOMAP), has been completed. A Bureau Report of Investigations including detailed geologic maps and cross sections of the two quadrangles will be published in June 1989.

In addition to the Bureau reports, results of the study are being presented at the national meeting of the Geological Society of America. A report on the Christmas Mountains caldera complex is being prepared for outside publication. The report and maps describe Tertiary dikes, sills, laccoliths, and volcanic rocks plus Cretaceous sedimentary rocks and Quaternary surficial deposits and will serve as a basis for future work on igneous petrogenesis and ore deposits in the area. These two quadrangles, which contain scattered silicic and mafic intrusions, include some of the more promising areas for mineral deposits in the Trans-Pecos region.

A major discovery during mapping was recognition of two small (approximately 4-km^2) but stratigraphically complex calderas in the Christmas Mountains. The calderas are unusual in that they are smaller, less silicic (quartz trachyte rather than

Bureau researcher Christopher D. Henry (top left) and a group of volcanology field trip participants at Burro Mesa Pouroff, Big Bend National Park.

rhyolite), and older (42 million years old, rather than 38 to 32 million years old, the age range of other calderas) than others in the Trans-Pecos magmatic province. The calderas were developed on the top of the elongate Christmas Mountains dome and probably resulted from ash-flow eruptions from a shallow laccolithic magma chamber.

Geologic Mapping in the Davis Mountains

Christopher D. Henry, Jonathan G. Price, and Jeffrey N. Rubin; John Sutter and Mick Kunk (U.S. Geological Survey, Reston, Virginia)

Mapping began in 1987 on a new, multiyear COGEOMAP project in the Davis Mountains. Mapping is designed for revision of the Fort Stockton and Marfa Sheets of the *Geologic Atlas of Texas*. The Davis Mountains contain several large-volume silicic volcanic units of controversial origin, including the Star Mountain, Sleeping Lion, Adobe Canyon, and Barrel Springs Formations. Similar and perhaps correlative units occur west (Bracks Rhyolite) and south (Crossen Trachyte) of the Davis Mountains. Whereas some of these units contain unquestionable ash-flow tuffs, others are composed of unusually extensive silicic lava flows. Detailed mapping should help to distinguish individual flows within the formations and to delineate their source areas. Argon 40-39 dating will be used to better define stratigraphic relations and to better date the overall timing of large-volume sililcic volcanism.

Other Geologic Investigations

Stratigraphy of Upper Pennsylvanian and Lower Permian Sequences in North-Central Texas

L. F. Brown, Jr.

During 1988 a manuscript titled "Regional Depositional Systems Tracts, Paleogeography, and Sequence Stratigraphy, Upper Pennsylvanian and Lower Permian Strata, North-Central Texas" completed peer review, and drafting of illustrations was begun. This report culminates many years of research in the cyclothemic sequences and attempts to integrate these results to provide a paleogeographic synthesis and a sequence-stratigraphic model to explain the complex stratigraphy of the Virgilian and Wolfcampian Series in the 22,000-mi^2 region of the Eastern Shelf and adjacent Midland Basin. This report will complement a report by L. F. Brown, Jr., R. F. Solis Iriarte, and D. A. Johns titled "Regional Stratigraphic Cross Sections, Upper Pennsylvanian and Lower Permian Strata (Virgilian and Wolfcampian Series), North-Central Texas" published in 1987 by the Bureau.

Development and Application of a He ICP Source for ICP/MS

David W. Koppenaal, Leslie F. Quinton, and Thomas L. Pinkston

Inductively coupled plasma mass spectrometry (ICP/MS) first became commercially available in 1983, and the Bureau was one of the first organizations in North America to obtain equipment to use this technique, which is rapidly becoming an important geochemical analysis tool. While conventional ICP/MS utilizes the argon ICP as an ionization source, investigations involving a possible alternative source using a helium ICP for ICP/MS were begun at the Bureau's Mineral Studies Laboratory (MSL) in 1986. Possible advantages associated with using a helium ICP include higher ionization efficiencies for the high ionization energy elements and fewer and less severe background interferences due to the essentially mononuclidic and low mass spectral position of the He^+ ions.

In 1988, the MSL obtained industrial support from one of the three ICP/MS manufacturers in the world, VG Elemental of Cheshire, England. Work conducted under this support focused on the design and development of an improved impedance matching system for the helium ICP. This work has necessitated complete redesign of the original system's variable capacitance drive system, resulting in a digital sensing circuit that appears more sensitive and accurate than the analog circuit used in the present impedance matching system. Examination of various nebulizer systems has established that several of the available nebulizers can be used with the helium ICP's, albeit at lower gas and solution flow rates. Finally, development work on a simpler, demountable, and replaceable helium ICP torch has continued and is hoped to result in a torch that will function under the extreme voltage and heat conditions inherent in using a helium ICP.

Applied Geodynamics Laboratory

Martin P. A. Jackson, laboratory director and project director; John G. Sclater; assisted by Shing-Tzong Lin

The Applied Geodynamics Laboratory (AGL) was established in September 1988. The facility is designed for scale-modeling investigations of the mechanics of tectonic and structural geologic processes. The new program will include components of basic research but will principally focus on applied scientific goals. The AGL will be equipped for both physical and mathematical modeling of a wide range of tectonic styles of deformation. Initially, the laboratory will concentrate on modeling tectonics in which gravity plays a significant role.

The AGL is housed in the Bureau's Mineral Studies Laboratory. Its nucleus is a high-speed, high-capacity centrifuge. This machine has been specially designed and equipped for tectonic modeling and is the only one suitable for this in the United States. It is equipped with stroboscopic lighting, viewing ports, slip rings, digital speed control with programmable acceleration and deceleration, and temperature control to within 1°C between 0°C and 40°C. The centrifuge is capable of accelerating models to more than 7,000 times the acceleration of gravity. Centrifuge modeling techniques allow the use of finely laminated materials stiff enough for intricate models to be constructed and sectioned after the experiments for three-dimensional examination. The University of Texas at Austin and the Bureau have provided funds to equip the laboratory. Mechanical test rigs will be used to derive data on effective viscosity, fracture strength, and frictional strength of the modeling materials. The laboratory also contains two deformation mechanical tables for modeling under normal gravity and equipment for density measurement and macrophotography.

During the first 2 years, the AGL's research program will focus on predicting the location, origin, mechanics, and evolution of hydrocarbon structural traps associated with salt tectonics. The investigation will examine trap development in a wide variety of salt structures, particularly allochthonous salt sheets, such as salt tongues and canopies. The physical models will be constructed from microlaminated materials. The hydrocarbon structural traps produced during centrifuging will have a resolution comparable to the detail in high-quality reflection seismic profiles. The results will be applicable to salt diapir provinces around the world. Funding and technical guidance for this program are being provided by an industrial associates consortium comprising 14 oil companies. The results of the modeling will be applied to the interpretation of seismic reflection data to assist in the exploration for hydrocarbons. The physical modeling results will also be used to generate synthetic seismogram images of the structural traps; this part of the program is planned as a cooperative venture with the University's Institute for Geophysics.

Horizontal section through a centrifuged model showing the internal structure of diapirs. The zebra stripes within the diapirs were originally horizontal and uniformly thick. Experiment performed at the University of Uppsala, Sweden.

Activities in 1988 were concerned with establishing the laboratory: planning research, procuring funding, recruiting staff for 1989, ordering, designing, and constructing equipment, and visiting other centrifuge-equipped tectonic laboratories in Queen's University, Canada, and University of Uppsala, Sweden. Equipment is expected to be installed and operational in April 1989, at which time experiments will begin.

Mechanics of Segmentation along Normal Faults

Jay A. Raney and Stephen E. Laubach

This project, funded by the Texas Higher Education Coordinating Board, investigates how segments of normal faults link to form larger faults and attempts to determine the location of subsidiary structures that develop along segmented normal faults. The research utilizes physical models, field studies, and computer simulations of segmented normal faults. The physical modeling will be carried out in the Bureau's recently established Applied Geodynamics Laboratory. Much of the equipment for the physical modeling was donated by Exxon Production Research Company. The irregular, or segmented, geometries of strike-slip faults have been discussed in previous studies, but similar work has not been accomplished on normal faults. A better understanding of the mechanics of normal faulting is important because of the relationship between normal faults and

hydrocarbons and other earth resources and because of the seismicity associated with normal faults in the western United States and throughout the world. Preliminary field studies have been completed, and modeling experiments are being designed.

Mined Lands Inventory

William R. Kaiser, project director; L. Edwin Garner, Mark W. Andreason, Robert H. Blodgett, and Mary L. W. Jackson

Texas is the nation's first and second ranking producer of crushed stone and sand and gravel, respectively. Surface mining of these and other commodities, in contrast to lignite and uranium mining, is not covered by current surface mining law and is unregulated by State or Federal agencies. In anticipation of eventual State regulation of industrial mineral mining, the Bureau is inventorying all noncoal and nonuranium mined lands to facilitate prioritization of them for detailed characterization and ultimate reclamation as well as to provide data to meet future legislative and regulatory needs. Abandoned and active mine sites are being inventoried to define health and safety and environmental issues.

The project began in June 1988 and is funded by the Surface Mining and Reclamation Division of the Railroad Commission of Texas. The current project covers a 48-county area in South Texas between the Colorado River and Rio Grande south of the Balcones Escarpment.

The project draws on a variety of source materials. Among the most important for locating mine sites are 7.5-minute topographic maps, low- and high-altitude aerial photographs (black-and-white and color-infrared), county soil survey reports, and unpublished Bureau materials on mined lands. Secondary sources of data central to the inventory are geologic, county highway, planimetric, color image, land use and land cover, flood, water well location, and surface water intake maps, mineral producers lists, and published mineral and water resources reports. Data from these sources are integrated with onsite visits for full characterization of mined lands.

Project activity has focused on acquisition of source materials and design of a computer-based inventory form. A detailed explanation describes each field of the inventory form, explains codes, and defines keywords. Mined lands are digitized to provide computer-prepared maps and area calculations of disturbed lands. Bexar and Colorado Counties are being used as case-study counties to develop and test inventory methodology.

Clay Diagenesis in Evaporite Environments

R. Stephen Fisher

This project, funded by the Texas Higher Education Coordinating Board, is designed to investigate clay diagenesis in high-ionic-strength aqueous solutions, evaluate the usefulness of altered clays as indicators of paleoenvironmental conditions, and explore specific mechanisms by which detrital silicates are transformed to authigenic phases.

The research encompasses four major areas of investigation: (1) chemical and mineralogic analyses of clay minerals from evaporite environments in the Palo Duro Basin and from various West Texas hydrocarbon reservoirs are being performed to determine the sequence of changes that occur as detrital clays react in evaporite environments; (2) alteration of feldspars in evaporite strata will be documented to determine whether these minerals are important sources of material for clay diagenesis; (3) laboratory experiments that simulate physical and chemical processes in evaporite environments will be performed to determine the mechanism by which alteration occurs and what factors control the reaction; and (4) geochemical modeling of reactions between marine evaporite brine and clay minerals will be conducted to investigate the thermodynamic stability fields of detrital and diagenetic clays and to relate observed clay diagenesis to experimental conditions.

Work to date shows that clay minerals can be used to distinguish between salt dissolution zones and areas where evaporites were never deposited. Clay minerals also record the passage of dolomitizing fluids into pre-Permian carbonate strata of the Palo Duro Basin. This finding presents an opportunity to date the time of dolomitization by Rb/Sr or K/Ar analysis of the authigenic clays.

Contract and Grant Reports

A variety of reports are prepared annually under terms of grants and contracts with sponsoring entities. Some of these reports are eventually published by the Bureau as part of its own series. Contract reports are kept on open file at the Bureau and may be consulted by interested persons. The following reports were prepared during the year:

Ayers, W. B., Jr., Kaiser, W. R., Swartz, T. E., and **Zellers, S. D.**, 1988, Geologic evaluation of critical production parameters for coalbed methane resources: The University of Texas at Austin, Bureau of Economic Geology, annual report prepared for the Gas Research Institute under contract no. 5087-214-1544, part I: San Juan Basin, 114 p.

Baumgardner, R. W., Jr., 1988, Relationship between radar lineaments, geologic structure, and in situ stress in East Texas: The University of Texas at Austin, Bureau of Economic Geology, topical report prepared for the Gas Research Institute under contract no. 5082-211-0708, 43 p.

Baumgardner, R. W., Jr., Tye, R. S., Laubach, S. E., Diggs, T. N., Herrington, K. L., and **Dutton, S. P.**, 1988, Site selection for GRI cooperative tight gas field research, volume II: Geologic characteristics of selected low-permeability gas sandstones: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Gas Research Institute under contract no. 5082-211-0708, 225 p.

Budnik, R. T., 1988, Tectonic history and regional tectonic framework of the Palo Duro Basin, Texas Panhandle: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651, 92 p.

Dutton, A. R., DuBar, J. R., Gustavson, T. C., and **Ruppel, S. C.**, 1988, Geology and hydrogeology of the Palo Duro Basin, Texas Panhandle—a synthesis of nuclear waste isolation feasibility studies, 1977-1987: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Office of the Governor of Texas under contract no. IAC(88-89)0716, 316 p.

Fisher, W. L., Finley, R. J., Seni, S. J., Ruppel, S. C., White, W. G., Ayers, W. B., Jr., Dutton, S. P., Kuuskraa, V. A., McFall, K. S., Godec, Michael, and Jennings, T. V., 1988, An assessment of the natural gas resource base of the United States: The University of Texas at Austin, Bureau of Economic Geology, ICF-Lewin Energy Division, ICF, Inc., and Argonne National Laboratory, report prepared for Office of Policy, Planning, and Analysis, U.S. Department of Energy, under contract no. 80622401, 77 p. plus appendices (bound separately), 126 p.

Galloway, W. E., and **Morton, R. A.**, 1988, Reservoir characterization of selected distal Frio Formation fields of Texas: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the U.S. Department of the Interior, Minerals Management Service, cooperative agreement no. 14-12-0001-30316, 42 p.

Gustavson, T. C., and Holliday, V. T., 1988, Depositional and pedogenic characteristics of the Quaternary Blackwater Draw and Tertiary Ogallala Formations, Texas Panhandle and eastern New Mexico: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651, 112 p.

Hamlin, H. S., and **Tyler, Noel**, 1988, Consolidation of geologic studies of geopressured-geothermal resources in Texas: The University of Texas at Austin, Bureau of Economic Geology, annual report prepared for the U.S. Department of Energy, Advanced Technologies Division, under contract no. DE-FC07-85NV10412, 45 p.

Henry, C. D., 1988, Volcanic geology of the Davis Mountains, Trans-Pecos Texas: first year report: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the U.S. Geological Survey under contract no. 14-08-0001-A0516, 50 p.

Hovorka, S. D., Fisher, R. S., and **Nance, H. S.**, 1988, Petrography and geochemistry of the Artesia Group, Palo Duro Basin, Texas Panhandle: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651, 79 p.

Jackson, M. P. A., Cornelius, R. R., and Talbot, C. J., 1988, Experimental modeling of diapirs, Parts 1 and 2: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651, 300 p. (Part 1, 202 p., Part 2, 98 p.).

Johns, D. A., 1988, Sandstone distribution and lithofacies of the Triassic Dockum Group, Palo Duro Basin, Texas: The University of Texas at

Austin, Bureau of Economic Geology, final report prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651, 94 p.

Kreitler, C. W., Akhter, M. S., and **Donnelly, A. C. A.,** 1988, Hydrologic-hydrochemical characterization of Texas Gulf Coast saline formations used for deep-well injection of chemical wastes: The University of Texas at Austin, Bureau of Economic Geology, Project Summary prepared for the U.S. Environmental Protection Agency, EPA/600/S2-88/046, 10 p.

Kreitler, C. W., Senger, R. K., and **Gustavson, T. C.,** 1988, Geologic and hydrologic investigations, Reese Air Force Base, Lubbock, Texas: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the U.S. Army Corps of Engineers under contract no. DACA56-88-M-0153, 62 p.

Kuuskraa, V. A., McFall, K. S., **Tyler, Noel,** and **Ambrose, W. A.,** 1988, A geologic assessment of reserve growth in Texas, South Central Basin Platform Play: ICF-Lewin and The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the U.S. Department of Energy/Fossil Energy, 125 p.

Milling, M. E., Hocott, C. R., Lucia, F. J., Miller, M. A., and **Neitzel, E. B.,** 1988, Major program elements for an advanced geoscience oil and gas recovery research initiative: The University of Texas at Austin, Geoscience Institute for Oil and Gas Recovery Research, an interim report prepared for the U.S. Department of Energy, Office of Fossil Energy, under contract no. DE-FG19-88BC14265, 31 p.

Morton, R. A., and **Jirik, L. A.,** 1988, Plio-Pleistocene depositional sequences of the southeastern Texas continental shelf: geologic framework, sedimentary facies, and hydrocarbon distribution: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Industrial Associates Project, 101 p.

Paine, J. G., Morton, R. A., and **White, W. A.,** 1988, Preliminary assessment of nonfuel minerals on the Texas continental shelf: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Louisiana Geological Survey under contract no. 14-12-0001-30404, 66 p.

Ruppel, S. C., 1988, Mississippian depositional history of the Texas Panhandle: a reappraisal: The University of Texas at Austin, Bureau of Economic Geology, topical report prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651, 15 p.

White, W. A., and **Calnan, T. R.,** 1988, Fluvial-estuarine sedimentation, Texas Gulf Coast: literature synthesis: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for Texas Parks and Wildlife Department, Resource Protection Division, in accordance with Interagency Contract (88-89)0820, 276 p., plus 52-p. appendix.

White, W. A., and **Calnan, T. R.,** 1988, Marsh sedimentation, Colorado and Trinity River deltas, Texas Gulf Coast: field studies: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for Texas Parks and Wildlife Department, Resource Protection Division, in accordance with Interagency Contract (88-89)0820, 68 p., plus 3 appendices.

The following Bureau publications served as final contract reports during 1988:

Conti, R. D., Herron, M. J., **Senger, R. K.,** and Wirojanagud, Prakob, 1988, Stratigraphy and influence of effective porosity on ground-water flow in the Wolfcamp brine aquifer, Palo Duro Basin, Texas Panhandle: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 169, 44 p.

Prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651.

White, W. A., Calnan, T. R., Morton, R. A., Kimble, R. S., Littleton, T. G., McGowen, J. H., and **Nance, H. S.,** 1988, Submerged lands of Texas, Bay City–Freeport area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands: The University of Texas at Austin, Bureau of Economic Geology Special Publication, 130 p.

Financial assistance was provided in part by (1) the General Land Office of Texas, with funding in accordance with section 305 of the Coastal Zone Management Act for Coastal Zone Management Program (CZMP), (2) the Governor's Budget and Planning Office, with grants in accordance with section 308 of the same act for the Coastal Energy Impact Program (CEIP); CZMP and CEIP funding was administered by the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce, and (3) the Minerals Management Service of the U.S. Department of the Interior; parts of the study were conducted in cooperation with the U.S. Geological Survey. Contract numbers with the General Land Office were IAC(80-81)-1201, IAC(78-79)-1910, IAC(78-79)-0539, IAC(76-77)-1244, and IAC(76-77)-0833. Contract numbers with the Governor's Budget and Planning Office were CZ80M935019, IAC(80-81)-0865, and IAC(78-79)-1210. The contract number with the Minerals Management Service is 14-12-0001-30070.

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 1988, the following 56 contracts, each of which had reporting requirements, were active at the Bureau:

Federal

"Characterization of the Geology and Hydrogeology of the Ogallala and Blackwater Draw Formations, Reese Air Force Base, Texas": supported by the U.S. Army Corps of Engineers.

"Comprehensive Assessment of Gas Resource Potential": supported by Argonne National Laboratory.

"Computerized Calculation of Lignite Resources, Jackson-Yegua Trend, East Texas": supported by the U.S. Geological Survey, U.S. Department of the Interior.

"Consolidated Research Program: U.S. Gulf Coast Geopressured-Geothermal Program": supported by the U.S. Department of Energy.

"Develop Guidelines for Wellhead Protection Areas in Confined Aquifer Setting": supported by the U.S. Environmental Protection Agency.

"Development of a Cooperative Geoscience Research Institute for Oil and Gas": supported by the U.S. Department of Energy.

"Geochemical Reactions between Injected Chemical Wastes and the Host-Rock Saline Aquifer": supported by the U.S. Environmental Protection Agency.

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

"Mapping Volcanic Centers in the Davis Mountains, Trans-Pecos Magmatic Province (FY88 and FY89)": supported by the U.S. Geological Survey, U.S. Department of the Interior (two contracts).

"Minesoil Sample Analysis for the Regulatory Compliance Evaluation in Texas": supported by the Office of Surface Mining, U.S. Department of the Interior.

"Regional Hydrologic Characterization of Saline Formations in the Texas Gulf Coast That Are Used for Deep-Well Injection of Chemical Wastes": supported by the U.S. Environmental Protection Agency.

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

"Studies Related to Continental Margins (years 1 through 6)": supported by the Minerals Management Service, U.S. Department of the Interior (five contracts).

"Texas Mining and Mineral Resources Research Institute (tenth and eleventh allotments)": supported by the Bureau of Mines, U.S. Department of the Interior (two contracts).

State

"Administrative and Geologic Assistance Associated with Establishing a Superconducting Super Collider in Texas": supported by the Texas National Research Laboratory Commission (two contracts).

"Assistance Associated with the Open Beaches Act": supported by the Attorney General's Office, State of Texas.

"Assistance to the State of Texas Associated with the Siting of a High-Level Nuclear Waste Repository in Texas": supported by the Governor's Nuclear Waste Programs Office.

"Continuation of Fluvial-Deltaic Sedimentation Studies, Texas Gulf Coast": supported by the Texas Department of Parks and Wildlife.

"Fluid Flow/Mass Transfer Models for Carbonate Reservoirs": supported by the University of Houston.

"Fluvial Sediments in Bays and Estuaries along the Texas Coast": supported by the Texas Department of Parks and Wildlife.

"Fort Hancock Investigation Plan for Geologic, Hydrologic, Geochemical, Geophysical and Geotechnical Studies": supported by the Texas Low-Level Radioactive Waste Disposal Authority.

"Geologic and Fluid Behavior Characteristics of Oil Reservoirs on University Lands": supported by The University of Texas System.

"Geotechnical Investigations of Low-Level Radioactive Waste Disposal in Texas": supported by the Texas Low-Level Radioactive Waste Disposal Authority.

"Impact of Artificial Recharge and Conjunctive Use of Surface Water and Ground Water on the Ground-Water Resources of the Colorado River Basin

in Wharton and Matagorda Counties": supported by the Lower Colorado River Authority.

"Inventorying Noncoal Abandoned Mine Lands": supported by the Railroad Commission of Texas.

"Mineral Resource Assessment of the Big Bend Ranch": supported by the Texas Department of Parks and Wildlife.

"Standardization and Transfer of Ground-Water-Related Computer Data Files to Texas Water Development Board Data Bank": supported by the Texas Water Development Board.

The Bureau was awarded the following grants by the Texas Higher Education Coordinating Board through the Advanced Research and Advanced Technology Programs:

"Accurate Modeling of Fluid Flow in Hydrocarbon Reservoirs and Aquifers with Scale Averaged Rock Properties"

"Clay Diagenesis in Evaporite Environments"

"Gas Saturation as a Limit on Pore-Fluid Composition and Diagenetic Alteration in Deep Sedimentary Environments"

"Mechanics of Segmentation along Normal Faults"

"Salt Tectonics on the Continental Slope, Northern Gulf of Mexico"

Private

"Applied Geodynamics Laboratory": supported by Conoco, Inc., Texaco, Inc., and Amoco Production.

"ARCO Contribution to the Geoscience Institute for Oil and Gas Recovery."

"Assessment of Gas Resources for Secondary Gas Recovery Technology": supported by the Gas Research Institute.

"Characterization of San Andres and Grayburg Reservoirs": supported by Mobil Exploration & Producing U.S., Inc., ARCO Oil and Gas Company, Amoco Production Company, Texaco, Inc., and Shell Oil Company.

"Develop a Geologic and Economic Model for Crude Oil Reserve Growth": supported by the U.S. Department of Energy through ICF-Lewin, Inc.

"Development and Application of a He ICP Source for ICP/MS": supported by VG Elemental.

"Development of an Atlas of Major Texas Gas Reservoirs": supported by the Gas Research Institute.

"Estimation of the Resource and Economically Recoverable Unswept, Mobile Oil": supported by the U.S. Department of Energy through ICF-Lewin, Inc.

"Genetic Stratigraphy, Depositional Systems, Structural Evolution, and Petroleum Exploration Potential: NW Gulf of Mexico Continental Shelf": research continued with new support from Consolidated Natural Gas and Total Minatome.

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

"Geologic Evaluation of Critical Production Parameters for Coalbed Methane Resources": supported by the Gas Research Institute.

"Geological, Geochemical, and Engineering Research in Support of Gulf Coast Co-Production Program": supported by the Gas Research Institute.

"Preliminary Assessment of Potential Nonenergy Minerals on the Texas Shelf": supported by the Minerals Management Service, U.S. Department of the Interior, through the Louisiana Geological Survey.

"Reservoir Characterization Research Laboratory": research continued with new support from Exxon Company, U.S.A.

"Stochastic Simulation of Fluid Pathways in Petroleum Reservoirs and Aquifers": supported by Cray Research, Inc.

"Support of the Pleasant Bayou Well Test Program of IGT": supported by the Institute of Gas Technology.

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 79-year history, the Bureau has published nearly 2,150 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, about 1.7 million publications have been distributed worldwide, mostly through direct sales. During 1988, about 25,000 volumes were distributed. The Bureau issued the following publications in 1988:

Reports of Investigations

RI 169. Stratigraphy and Influence of Effective Porosity on Ground-Water Flow in the Wolfcamp Brine Aquifer, Palo Duro Basin, Texas Panhandle

by R. D. Conti, M. J. Herron, R. K. Senger, and Prakob Wirojanagud. 44 p., 29 figs., 2 tables, 3 appendices ($2.50)

Investigation of the relations between stratigraphy, effective porosity, and hydrology of Wolfcamp strata of the Palo Duro Basin

Predominantly carbonate Wolfcamp strata constitute the upper part of a deep-basin brine aquifer that underlies bedded salts of the San Andres Formation, which until recently was being considered as a host for high-level radioactive waste. In this Department of Energy-funded project, the authors studied heterogeneity of effective-porosity distributions and used them to define potential reservoir fairways and their relation to Wolfcampian depositional systems and major diagenetic facies. The results—incorporated in computer modeling of ground-water flow—yielded estimates of basinwide travel times and provided data necessary for estimating total effective pore volume, which equals the quantity of mobile fluids in the aquifer. The authors established the Wolfcamp stratigraphic boundaries by correlating lithofacies throughout the Palo Duro Basin with those of adjacent basins. Cores from four DOE test holes, geophysical logs, and lithologic descriptions from sample logs were the main data sources for discerning lithologic/hydrologic continuity. Beyond high-level waste isolation considerations, results of this study are directly applicable to establishing a regional context for potential reservoir exploration and underground hazardous waste injection programs. This work was supported by the U.S. Department of Energy Salt Repository Office.

RI 170. Lithostratigraphy and Paleoenvironments of Upper Paleozoic Continental Red Beds, North-Central Texas: Bowie (New) and Wichita (Revised) Groups

by T. F. Hentz. 55 p., 24 figs., 3 tables, 1 plate, 1 appendix ($3.00)

First comprehensive investigation into the regional stratigraphic framework and depositional environments of exposed upper Pennsylvanian and lower Permian continental rocks of the Eastern Shelf (Midland Basin) in North-Central Texas. Study details new and revised lithostratigraphy presented in the Wichita Falls-Lawton Sheet of the Geologic Atlas of Texas

Upper Paleozoic continental red beds are exposed in a 10-county area between the Brazos and Red Rivers in North-Central Texas. Historically, the lithologic contrast between these strata and contemporaneous marine and deltaic facies to the south has impeded surface correlation. Through rigorous outcrop and photogeologic mapping, regional correlation of continental sandstone units with the northern terminations of marine limestone marker beds allowed the author to establish a stratigraphic tie with the dominantly marine sections exposed within the Colorado River and Brazos River valleys. The author

formally defines a new continental group, the Bowie Group (equivalent to the marine and deltaic Cisco Group), and its two component formations. He also differentiates the Wichita Group and its three new formations from the open-marine beds of the Albany Group (formerly undifferentiated Wichita-Albany Group). Areal and stratigraphic range, lithologic characteristics, and stratotypes are presented for each newly defined unit. The red beds collectively constitute a continuous depositional tract of lower piedmont to shallow-shelf facies. The author describes several paleoenvironments, including four varieties of fluvial-channel systems, floodplain, floodbasin ponds/back-swamps, tidal mud flats, coastal ponds/marshes, tidal/distributary channels, and nearshore lime muds. These deposits are of special interest to vertebrate paleontologists because they contain the oldest assemblage of abundant reptile and amphibian fossils in the world.

RI 171. Heterogeneous Deep-Sea Fan Reservoirs, Shackelford and Preston Waterflood Units, Spraberry Trend, West Texas

by Noel Tyler and J. C. Gholston. 37 p., 29 figs., 3 tables ($3.00)

Geological characterization of reservoir and production attributes of the Shackelford and Preston waterflood units, southeastern Midland County, West Texas

These two units, which are operated by Mobil Producing Texas and New Mexico, are part of the Permian Spraberry Trend. Conventional reserves in the Spraberry are estimated to be almost 60 million barrels of oil, and more than 4 billion barrels of unproduced mobile oil remain, making the Spraberry a prime target for extended conventional recovery from untapped or poorly drained reservoir compartments. The authors determined the stratigraphy of the formation, mapped sand distribution trends, and determined from cores and logs the extent and composition of facies that compose the principal reservoir units. Geological characteristics of the Spraberry were then integrated with production data to examine the relationship between the geology of the formation and oil recovery as well as sedimentary constraints on oil recovery. The authors recommend that reserve growth might best be attained by siting new geologically targeted infill wells in the dip-elongate depositional axes and by selectively recompleting existing wells to produce bypassed oil in undrained reservoir compartments in areas of poorer reservoir quality. The authors note that additional recovery of just 6 percent of the 1 billion barrels of feasibly recoverable movable oil will double the remaining reserves of the Spraberry.

RI 172. Geological Characterization of Permian Submarine Fan Reservoirs of the Driver Waterflood Unit, Spraberry Trend, Midland Basin, Texas

by E. H. Guevara. 44 p., 26 figs., 3 tables, 2 appendices ($3.00)

Geological characterization and assessment of the relationship between reservoir stratigraphy and oil recovery of the Driver waterflood unit of the Spraberry Trend, Midland Basin, West Texas

In this companion study to RI 171, the author focuses on the Driver waterflood unit, which is located in Midland, Glasscock, Upton, and Reagan Counties and is part of the giant Spraberry Trend currently being studied by the Bureau. Gamma-ray logs and scout cards from more than 350 wells and slabbed cores from 2 wells, along with core analyses and production data, provided the main sources of information for the study. Fifteen log-defined genetic-stratigraphic operational units were delineated in the Spraberry Formation and were correlated throughout the study area to define the stratigraphic framework. The text presents net sandstone and siltstone maps, cross sections, depth plots of core analyses, and maps of production data. The author describes the depositional systems and hydrocarbon distribution in the Driver unit (currently operated by Standard Oil), details the influence of reservoir stratigraphy on oil recovery, and outlines opportunities for additional recovery. He notes that reservoir management strategies must take into account the stratigraphic heterogeneities of accumulations in the unit. He concludes that a program of selective recompletions and infill drilling based on knowledge of both reservoir stratigraphy and natural fractures is the key to improving oil recovery from the Driver unit in particular and from the Spraberry Trend in general. This investigation was funded by The University of Texas System.

RI 173. Centrifuge Modeling of the Effects of Aggradation and Progradation on Syndepositional Salt Structures

by M. P. A. Jackson, C. J. Talbot, and R. R. Cornelius. 93 p., 67 figs., 9 tables, 7 appendices ($5.00)

Description and analysis of 16 experiments using scaled centrifuged models to simulate the effect of variable sedimentary loading on the external geometry, kinematics, and dynamics of syndepositional salt structures in the northern Gulf of Mexico basin

Modeling conducted at the University of Uppsala, Sweden, used an innovative technique, stepwise centrifuge modeling, which allowed the simulation of salt-dome growth during episodic sedimentation. Salt tectonics during both episodic aggradation and progradation were reproduced three-dimensionally for the first time. The report reexamines the concept of diapiric downbuilding and presents the results of experiments comparing upbuilding and downbuilding. The modeling also investigated edge effects and simulated static differential loading. The report describes in detail the methodology of centrifuge modeling, including scaling and rheology. Results showed that downbuilding (syndepositional) domes rose slower and formed closer together, formed double-stalked domes more easily, and developed exposed walls and peripheral hanging lobes more easily than did upbuilding (postdepositional) structures. In the absence of edge effects, the model diapirs were connected at depth by a polygonal system of ridges, a phenomenon thought to be present in nature. The formation of salt tongues spreading laterally was also simulated under prograding sedimentary loads. These results are significant to understanding the structure of Gulf Coast interior basins and the allochthonous salt tongues in the northern Gulf of Mexico. Funding for the research was provided by the U.S. Department of Energy Salt Repository Project Office.

RI 174. Middle-Upper Miocene Depositional Sequences of the Texas Coastal Plain and Continental Shelf: Geologic Framework, Sedimentary Facies, and Hydrocarbon Plays

by R. A. Morton, L. A. Jirik, and W. E. Galloway. 40 p., 24 figs., 2 tables, 1 appendix, 7 plates ($6.00)

Interpretation of depositional systems and structural styles and discussion of the hydrocarbon distribution and potential of the middle-upper Miocene outcrop belt and its subsurface equivalents

The authors synthesized nearly 1,500 geophysical logs to establish a genetic stratigraphic framework for middle-upper Miocene sediments and hydrocarbon resources. Their interpretations are presented in three structural cross sections and in numerous quantitative lithofacies maps and interpretive drawings. Paleontologic summaries of several hundred wells aided definition of chronostratigraphic relationships and paleobathymetric zones. Nine principal depositional systems are delineated and discussed in terms of sea-level fluctuations. In the second half of the text, the authors discuss the origin and distribution of hydrocarbons within the middle-upper Miocene sequences. A comprehensive table summarizes the geologic characteristics and remaining potential of the nine identified middle-upper Miocene oil and gas plays. The authors conclude that the Miocene has significant remaining exploration potential; they note, however, that production within the Miocene has typically been limited to numerous small gas fields. Partial financial support for this study was provided by an industrial associates group that included Amoco Production Company USA, ARCO Exploration and Technology Company, Conoco Incorporated, Consolidated Natural Gas, the Louisiana Land and Exploration Company, Mobil Producing Texas and New Mexico Incorporated, Pennzoil Exploration Company, Tenneco Oil Company, Texaco USA, Total Minatome Corporation, and the U.S. Geological Survey.

RI 175. Depositional and Ground-Water Flow Systems of the Carrizo–Upper Wilcox, South Texas

by H. S. Hamlin. 61 p., 47 figs., 3 tables ($3.50)

Interpretation and regional delineation of fluvial depositional systems, ground-water flow patterns, and hydrochemical evolution in the Carrizo–upper Wilcox in South Texas

To characterize the depositional systems and facies of the Eocene Carrizo Formation and the stratigraphically equivalent, upper part of the Wilcox Group, the author synthesized more than 700 electric logs and surveyed available outcrops. The study encompasses the surface and subsurface extent of the Carrizo–upper Wilcox throughout the Rio Grande Embayment updip from the Wilcox growth-fault zone. A series of cross sections and maps illustrate structural configuration, interval thickness, sandstone geometries, and facies distributions. Hydraulic and hydrochemical data from 144 water wells provided a foundation for this examination of flow patterns, recharge and discharge, and ground-water chemistry and evolution, all of which are displayed on numerous maps, graphs, and cross sections. The author concludes that subtle relationships between Carrizo depositional and ground-water flow systems are largely masked by the predominance of flow in massive-quartz-rich fluvial channel-fill sandstones. High levels of recharge and down-gradient flow through these transmissive sandstones have created an unusually extensive and deep fresh-water aquifer that is an important resource in South Texas. The Carrizo–upper Wilcox interval is also a repository for uranium and hydrocarbons. Information presented in this report will be helpful in successfully and efficiently developing these resources.

RI 176. Hydrogeology of Barbers Hill Salt Dome, Texas Coastal Plain

by H. S. Hamlin, D. A. Smith, and M. S. Akhter. 41 p., 29 figs., 9 tables, 3 appendices ($2.50)

Detailed description of subsurface geology and hydrology of the Barbers Hill area, Chambers County, Texas

Barbers Hill salt dome has a long history of resource exploitation, including oil and brine production, storage of hydrocarbons in solution-mined caverns within the salt stock, disposal of brine into the cap rock, and fresh ground-water production from shallow aquifer sands that surround the dome. Abundant geologic and hydrologic data derived from these activities were used by the authors to document local hydrogeology and to consider possible perturbations of natural ground-water flow systems. The geometry and composition of the salt stock and cap rock and the structural and stratigraphic configurations of enclosing Cenozoic clastic sediments are described and illustrated. Potential permeable interconnections between the brine-saturated cap rock and adjacent, fresh-water aquifers are delineated. Hydraulic heads and gradients and numerical modeling reveal a pronounced potential for flow away from the cap rock and toward the fresh-water aquifers. Hydrochemical analyses from near-dome fresh-water wells indicate that dome-related saline waters are entering the sand aquifers. Recent dramatic increases in dissolved sodium and chloride in several water wells suggest that cap-rock brine disposal is accelerating aquifer salinization. The purpose of this study, which was funded by the Texas Water Commission, is to present information that could be useful in making decisions concerning the future use of subsurface resources at Barbers Hill.

RI 177. Hydrogeology and Hydrochemistry of the Ogallala Aquifer, Southern High Plains, Texas Panhandle and Eastern New Mexico

by Ronit Nativ. 64 p., 35 figs.,1 table ($3.00)

Assessment of the geology, hydrology, and hydrochemistry of the Ogallala aquifer

The Ogallala aquifer, which underlies the High Plains of Texas and New Mexico and is that area's main source of water, is being severely depleted by extensive pumpage for irrigation. Contamination from evaporating saline lakes, agricultural chemicals and fertilizers, and oil field brines is locally affecting the water quality of the Ogallala aquifer, and its impact may increase in the future as contaminants move downward toward the water table. These concerns prompted this investigation into the hydrogeology and hydrochemistry of the Ogallala aquifer. The

project entailed compiling permeability and porosity, water-level, and water-chemistry data from published sources and computerized (USGS and TNRIS) data bases. Potential contamination by oil field brines that may affect Ogallala hydrochemistry was studied using the results of 447 chemical analyses of water samples from all major oil-producing formations in the Southern High Plains. New data collected for this study included 76 ground-water samples from the Southern High Plains and 10 samples from the Rolling Plains and 251 precipitation samples collected from 5 stations. Results indicate that the hydrology and hydrochemistry of the Ogallala aquifer are mainly controlled by the topography of the mid-Tertiary erosional surface and by the lithology of Ogallala sediments. In areas where the Ogallala aquifer is thin, cross-formational flow from the underlying Cretaceous formations affects the water composition. Secondary factors such as contamination from oil field brines or from agricultural fertilizers, as well as evaporation where the water table is relatively shallow, will locally affect the water quality of the Ogallala aquifer. The U.S. Department of Energy Salt Repository Project Office provided the funding for this research.

RI 178. Effects of Facies and Diagenesis on Reservoir Heterogeneity: Emma San Andres Field, West Texas

by S. C. Ruppel and H. S. Cander. 67 p., 52 figs., 3 tables, 2 appendices, 11 plates ($6.75)

Documentation of the distribution and extent of porous facies within the San Andres reservoir in the Emma field, Permian Basin, West Texas, and the diagenetic and depositional processes leading to their development

This three-part study examines the facies and depositional setting, diagenesis and geochemistry, and reservoir geology of the Emma San Andres oil field in West Texas. Although nearly 20 million barrels of oil has been produced from this reservoir since its discovery in 1939, an estimated 15 million barrels remains. The authors state that this remaining resource is unequally distributed between two distinct reservoirs in the upper San Andres. Despite pervasive diagenesis, porosity in these zones is largely a function of variations in original depositional texture. The authors conclude that effective exploitation of the remaining oil must focus on selective completion and recompletion in these two zones. Funding for this study was provided by The University of Texas System.

RI 179. An Assessment of the Natural Gas Resource Base of the United States

by R. J. Finley, W. L. Fisher, S. J. Seni, S. C. Ruppel, W. G. White, W. B. Ayers, Jr., S. P. Dutton, M. L.W. Jackson, Nancy Banta, V. A. Kuuskraa, K. S. McFall, Michael Godec, and T. V. Jennings. 69 p., 34 figs., 27 tables, 5 appendices ($4.00)

An evaluation of the natural gas resource base of the United States that includes an economic assessment of gas available in two wellhead price categories

This assessment includes proved natural gas reserves in known reservoirs, inferred reserves, unconventional resources, reserve growth potential in nonassociated and associated reservoirs, and undiscovered resources. In addition to using existing estimates derived using traditional methodologies, the assessment also considered and quantified a new category, reserve growth in heterogeneous reservoirs. Reserve growth potential was based on evaluation of more than 300 plays, or groups of geologically related reservoirs, including some 10,000 fields. The reserve growth resource can be accessed through infill drilling and recompletion of bypassed zones. Estimates of recoverability within each resource category, and of components of each category, accessible at different price ranges, were consistently conservative, particularly for unconventional resources. A 17-member national Review Panel aided in estimating technically recoverable natural gas in each price category and judged resource recoverability at 1987 wellhead prices of less than $3.00/Mcf and $3.00–$5.00 Mcf. Results indicate that a technically recoverable reserve and resource base of 1,059 trillion cubic feet (Tcf) of natural gas exists in the lower 48 states. Nearly 600 Tcf of natural gas was judged recoverable at less than $3.00/Mcf. Alaskan reserves and resources were assessed separately. Funding for this study was provided by the U.S. Department of Energy through a contract with Argonne National Laboratory and a subcontract with the Bureau.

Special Publication

Submerged Lands of Texas, Bay City–Freeport Area: Sediments, Geochemistry, Benthic Macroinvertebrates, and Associated Wetlands

by W. A. White, T. R. Calnan, R. A. Morton, R. S. Kimble, T. G. Littleton, J. H. McGowen, and H. S. Nance. 130 p., 65 figs., 16 tables, 3 appendices, 6 plates ($12.50)

Detailed inventory of submerged lands and associated wetlands in the Bay City–Freeport area of the Texas Coastal Zone.

State-owned submerged lands of Texas encompass nearly 6,000 square miles and extend 10.3 miles from the Gulf shoreline on the inner continental shelf. This atlas, which focuses on the Bay City–Freeport area of the Coastal Zone, is the fifth in a series of submerged lands atlases to provide comprehensive sedimentological, geochemical, and biological data for management of coastal areas. Researchers collected and analyzed 6,700 benthic sediment samples across the submerged lands of Texas, from the Rio Grande to Sabine Lake, to map and describe sediment distribution, concentrations of selected major and trace elements, and benthic macroinvertebrate populations. Adjacent wetlands were delineated using stereoscopic, color-infrared positive transparencies provided by the National Aeronautics and Space Administration and are depicted on a full-color map along with the distribution of benthic macroinvertebrate assemblages and species diversity in submerged lands. Research was partly funded by the General Land Office and the Governor's Budget and Planning Office of the State of Texas (through programs administered by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce) and by the Minerals Management Service, U.S. Department of the Interior.

Geological Circulars

GC 88-1. Geology of Damon Mound Salt Dome, Texas: Evidence of Oligocene to Post-Pleistocene Episodic Diapir Growth

by E. W. Collins. 24 p., 19 figs., 1 appendix ($2.50)

Geological investigation of the stratigraphy, cap-rock characteristics, deformation and growth history, and growth rate of a shallow coastal diapir

Damon Mound salt dome, located in Brazoria County, has salt less than 600 feet and cap rock less than 100 feet below the surface; a quarry over the dome provides excellent exposures of cap rock as well as overlying Oligocene to Pleistocene strata. These conditions make it ideal as a case study for other coastal diapirs that lack bedrock exposures. Such investigations are important because salt domes are currently being considered by chemical waste disposal companies as possible storage and disposal sites. In this Texas Water Commission-funded study, the author reviews previous research, presents additional data on the subsurface and surface geology at Damon Mound, and evaluates Oligocene to post-Pleistocene diapir growth. Approximately 110 geophysical logs compose the subsurface data base that was used to construct cross sections and isopach maps of Damon Mound. Descriptions of stratigraphy by earlier researchers were verified, and additional measured sections and cross sections were made. On the basis of his findings, the author concludes that Damon Mound salt dome is probably in the postdiapir stage of dome growth and that growth probably continued through the Pleistocene. Strata of different ages lie directly on cap rock, indicating the likelihood that pulses of dome growth accompanied by erosion and subsequent deposition probably occurred during diapir growth.

GC 88-2. Subsidence and Collapse at Texas Salt Domes

by W. F. Mullican III. 36 p., 25 figs., 3 tables, 2 appendices ($2.50)

Description of the mechanisms and extent of natural and man-induced subsidence and collapse at Texas salt domes

In the Houston diapir province, Frasch mining has caused subsidence bowls and collapse sinkholes at 12 of the 14 sulfur-productive domes. Understanding the structural and hydrologic instability that results at the surface and subsurface is crucial in evaluating the suitability of salt domes as repositories for waste disposal. Part of the Bureau's Coastal Salt Dome Program, this study used aerial photographs, remote-sensing methods, historical and modern topographic maps, and field checks to detect subsidence and collapse associated with natural salt diapiric processes and commercial resource recovery and to determine which processes are likely to reduce the stability and integrity of hydrologic and structural barriers around salt diapirs. Figures and tables illustrating the extent and evolution of subsidence and collapse, along with photographs showing their effects, highlight the text discussion of the salt domes detailed in this study—Boling, Orchard, Moss Bluff, Spindletop, Hoskins Mound, Fannett, Long Point, Nash, High Island, Bryan Mound, Clemens, and Gulf. The author concludes that Frasch sulfur mining from cap rocks causes the most catastrophic subsidence and collapse and that subsidence over salt domes included processes ranging from trough subsidence to various types of subsurface caving. He also concludes that salt domes characterized by subsidence and collapse are unfavorable sites for storage or disposal of hazardous wastes.

GC 88-3. Hydrogeology and Hydrochemistry of Cretaceous Aquifers, Texas Panhandle and Eastern New Mexico

by Ronit Nativ and Gay Nell Gutierrez. 32 p., 19 figs., 5 appendices ($2.50)

Hydrologic and hydrochemical study of the Cretaceous Edwards, Duck Creek, and Kiamichi Formations in Texas and eastern New Mexico

Cretaceous rocks in the southern part of the Southern High Plains contain aquifers that are an important source of potable water where the Ogallala aquifer is thin or missing. Despite intensive pumpage for irrigation during the past 40 years that caused water-level declines in some areas, water levels actually increased in other areas. Water in the Cretaceous aquifers is commonly brackish; in areas where the water table is shallow, high amounts of nitrate and even arsenic exist in the ground water. The water quality is controlled mainly by thickness of the vadose zone, but recharge from the underlying Dockum and overlying Ogallala affects the water chemistry in some areas. The purpose of this study was to present a new hydrologic model of the three Cretaceous aquifers and to assess their contribution to the hydrology of the region. Funding for this circular was provided by the U.S. Department of Energy Salt Repository Project Office.

Mineral Resource Circular

MRC 80. The Mineral Industry of Texas in 1986

by J. P. Ohl and M. W. McBride. 15 p., 1 figure, 12 tables (free on request)

Annual summary of all nonfuel minerals of Texas

This circular is a preprint of the chapter on Texas in the Minerals Yearbook 1986 of the U. S. Bureau of Mines. It was produced through a cooperative agreement between the U. S. Bureau of Mines and the Bureau of Economic Geology.

Cross Sections

Regional Structural Cross Sections, Mid-Permian to Quaternary Strata, Texas Panhandle and Eastern New Mexico: Distribution of Evaporites and Areas of Evaporite Dissolution and Collapse

by D. A. McGookey, T. C. Gustavson, and A. D. Hoadley. 17 p., 6 figs., 1 table, 1 appendix, 12 cross sections ($9.50)

Twelve regional cross sections (with text) of the Palo Duro, Dalhart, and Anadarko Basins illustrating the tabular geometry of Permian evaporite beds, areas where salt has been lost by dissolution, and the effects of dissolution-induced subsidence on Permian and post-Permian strata

The authors identify areas of dissolution beneath the High Plains, the Caprock Escarpment, the Rolling Plains, the Pecos Plains, and along the Canadian River valley. The cross sections are printed at a vertical scale of 1 inch equals 400 feet and a horizontal scale of 1 inch equals approximately 8 miles and were constructed using geophysical logs, sample logs, and surficial geologic data. The study was funded by the U.S. Department of Energy Salt Repository Project Office.

Geologic Quadrangle Map

GQ 54. Structural Geology of Sierra del Carmen, Trans-Pecos Texas

by A. R. Moustafa. 28 p., 13 figs., 1 table, 3 plates ($2.00)

Photogeologic and field mapping of the stratigraphy and structure of the Sierra del Carmen, Brewster County, Trans-Pecos Texas

As part of the Texas Lineament, the Sierra del Carmen underwent both Laramide and Basin and Range deformations, which created numerous folds, faults, monoclines, and grabens in the area. The author mapped and distinguished between Laramide and Basin and Range structures, investigated the process of their formation, and assessed the influence of the Texas Lineament on the Sierra del Carmen. Field relations are depicted on a 1:48,000-scale geologic map and on 1 northwest-oriented and 10 east-northeast-oriented cross sections. A structure-contour map on the top of the Santa Elena Formation shows field-measured dips and strikes and topographic contours. The accompanying text describes the Cretaceous, Tertiary, and Quaternary stratigraphy of the area, summarizes the results of petrofabric analysis of calcite twinning, and provides structural analysis and interpretation of monoclines, folds, and faults in the Sierra del Carmen and adjacent areas. Funding for the research was provided by Tenneco Oil Company, the Gulf Coast Association of Geological Societies, and The University of Texas Geology Foundation.

Services

Core Research Center

The Core Research Center (CRC) houses one of the largest public collections of subsurface geological materials in the United States. The CRC and adjacent repository are open from 8:00 a.m. to 5:00 p.m. Monday through Friday. Viewing, thin-section, slabbing, photographic, radiographic, and gamma-scan facilities are open to the public. Information about holdings, policies, and computer listings may be obtained by calling Allan R. Standen, Curator, at (512) 471-1534. A brochure describing the CRC is available on request.

Approximately 6,100 cores and 53,000 well cuttings are available for study at the CRC and may be viewed onsite or checked out for up to 6 weeks. Patrons are asked to provide results of analyses of borrowed material to the CRC, which then become part of the center's reference material. Information about wells is stored in a data base, and customized data-base searches may be requested.

During 1988, the CRC received more than 300 non-Bureau visitors. Transactions involving CRC inventory included material from 776 wells and required the transfer of more than 12,000 boxes of core to and from viewing and shipping areas. Core processing, including the slabbing and reboxing of wells, involved 500 cores, totaling about 40,000 linear feet. The thin-section lab produced more than 2,400 thin sections for both Bureau and non-Bureau patrons.

New acquisitions of core and cuttings in 1988 total more than 80,000 linear feet and include material from 650 wells in counties in Texas, Alabama, Arizona, Arkansas, California, Colorado, Louisiana, Montana, New Mexico, Oklahoma, Tennessee, and Wyoming. Materials were donated by American Exploration, ARCO, Bell Petroleum, Bracken Energy, Brock Exploration, Canfill/Rogers, Cities Service Oil, Bill Forney, Gunn Oil Corporation, Home Petroleum, Hurd Enterprises, Internorth, Inc., Kerr-McGee, Marathon Oil, Mobil Oil, Morrison-Knudson, Pittsburgh Plate and Glass, Plains Petroleum, Reservoirs Inc., Restech, Santa Fe Minerals, Sergio Collier, Spectrum Resources, Sun Oil, Tesoro Petroleum, Texas Department of Water Resources, Texas Gulf and Metals, Texas Low-Level Waste Disposal Authority, TXO Production, Union Oil of California, University of California at Riverside, The University of Texas at Arlington, U.S. Army Corps of Engineers, U.S. Borax, U.S. Department of Energy, U.S. Geological Survey, U.S. Steel Uranium Operations, W.H. Wood, and Marshall R. Young.

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 is capable of providing near-complete geochemical, mineralogical, and textural characterization of most geological materials. The MSL is currently staffed by Acting Chief Chemist Steven W. Tweedy and two other chemists. It includes several major instrument capabilities, including inductively coupled plasma optical and mass spectrometry (ICP-OES, ICP-MS), stable isotope mass spectrometry, electron microprobe analysis, scanning electron microscopy examination, and X-ray diffractometry. Complete wet-chemical analysis, coal/fuel analysis, sample comminution, and fire assay capabilities also exist within the MSL. These services are available to the Texas geological community but are primarily intended for support of Bureau research programs.

Many Bureau programs were supported by MSL analysis and characterization efforts during 1988. Among these are the West Texas Waste Isolation program, the Texas Mining and Mineral Resources Research Institute, and the Submerged Lands and Low-Level Waste projects. In addition to supporting Bureau projects, MSL staff conducted a minesoil sample analysis project for the U.S. Department of the Interior (Office of Surface Mining Reclamation and Enforcement) and provided analytical services for the Institute of Gas Technology's Pleasant Bayou well test. Research activities continued on the development and application of a helium-ICP ion source for inorganic mass spectrometry, as funded by VG Elemental of Cheshire, England.

The MSL continued its participation in several professional societies and associations devoted to standardizing and developing analytical methods. The MSL is a member of the International Geostandards Working Group and also participates in

the work of several committees of the American Society for Testing and Materials.

Public Information

Requests for information about Texas geology and energy, mineral, and land resources come to the Bureau from geologists, engineers, educators, students, landowners, and other interested individuals, as well as from companies, 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. Mary W. McBride, 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 1988, approximately 1,600 such requests were handled by McBride.

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 Carolyn Condon, 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 14,000 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, as well as unpublished open-file reports and contract reports prepared by the Bureau for various contracting agencies.

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 work data used in preparing Bureau publications are on open file for staff and public use. Topographic and geologic maps, aerial photographs, and Landsat images are also 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.

In 1988, Reading Room staff cataloged, indexed, entered into a computer data base, and shelved more than 1,000 items. The current circulation computer data base includes more than 2,000 items that have been checked out of the Reading Room by Bureau staff. More than 150 items including photographs, negatives, slides, glass negatives, lantern slides, and manuscript materials from the collections of Walter Scott Adkins, W. Armstrong Price, and the Bureau were transmitted to the University's Barker History Center for archival and preservation.

Geophysical Log Facility

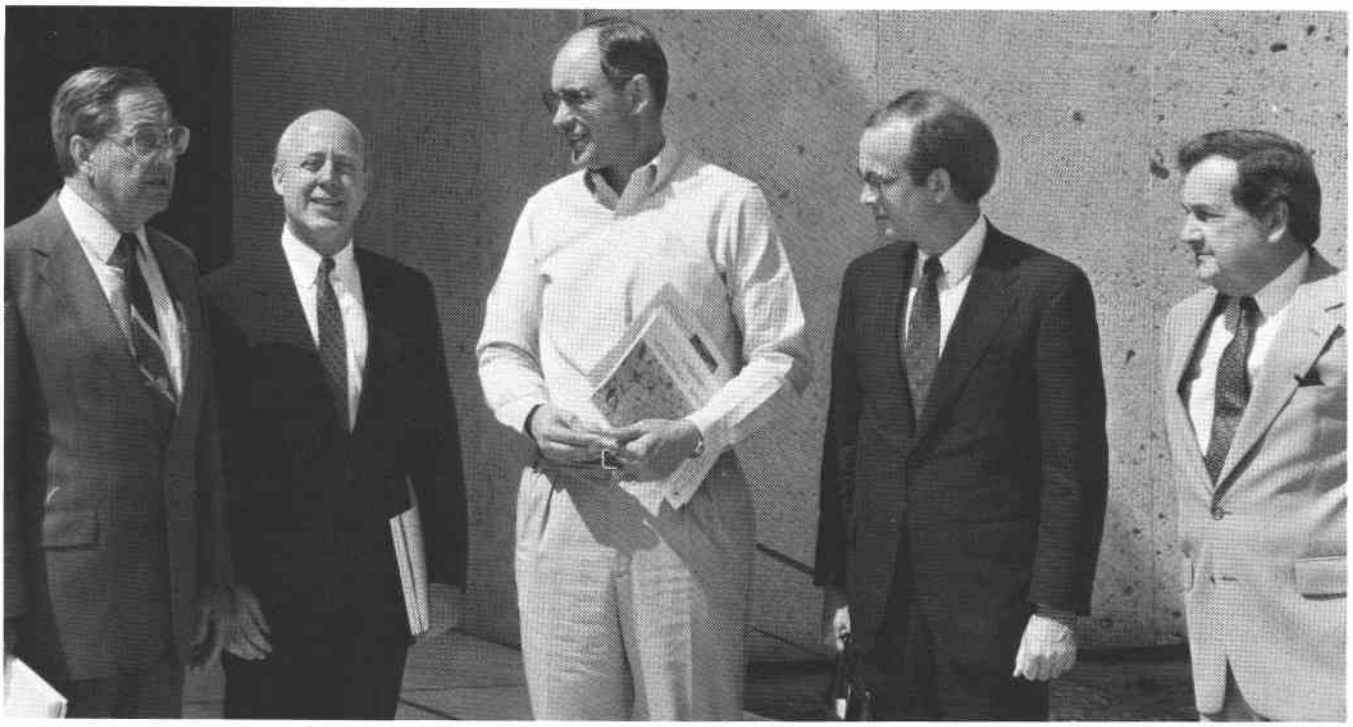
The Geophysical Log Facility (GLF), managed by Allan R. Standen, is housed in the Bureau's Reading Room/Data Center. The facility was established by State legislation, effective September 1, 1985, that requires all operators of oil, gas, and geothermal wells to provide the Railroad Commission of Texas 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 well logs. The logs are 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 1988, the facility had accumulated approximately 40,000 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

Texas Named Site for Superconducting Super Collider

Texas has been named the preferred site for the scientific world's largest project, the $4.4 billion superconducting super collider (SSC). The site is in Waxahachie, Ellis County, about 40 mi southeast of the Dallas-Fort Worth International Airport. The largest particle accelerator ever to be built, the SSC will be a 53-mi-long racetrack-shaped tunnel buried at depths from greater than 25 ft to greater than 120 ft underground. For several years, the Bureau has played an influential role in seeking a geologically suitable site in Texas for the SSC. Early in the site-selection process, Bureau Director William L. Fisher chaired a preliminary site evaluation committee consisting of scientists from The University of Texas at Austin, Texas A&M University, Rice University, and the University of Houston. The committee was established by Peter T. Flawn, then-President of The University of Texas at Austin and former Director of the Bureau. The committee's report, conducted for the Governor, indicated that Texas had several potentially attractive sites for the SSC. In 1986 Flawn was appointed by the Governor to chair the Texas National Research Laboratory Commission (TNRLC), and Fisher was named by the Governor to the Texas Scientific Advisory Council for the SSC. As interest in the SSC grew, Edward C. Bingler, Deputy Director of the Bureau, was given a leave of absence from the Bureau to act as Executive Director of TNRLC, the commission charged with preparation of a proposal to the U.S. Department of Energy (DOE) for siting the SSC in Texas. Douglas C. Ratcliff, Associate Director for Administration at the Bureau, assisted in administrative and financial matters. After evaluation of many Texas sites, TNRLC chose two for presentation to DOE. Bureau geologists served as consultants to the two site committees. When the Ellis County site was chosen as one of eight "finalists" by DOE, Bureau geologists Alan R. Dutton, Edward W. Collins, L. Edwin Garner, and Bernd C. Richter addressed geological and hydrological questions posed by DOE regarding the site and led two field trips to the area for onsite inspection by DOE personnel and their representatives.



Congressmen Chapman and Boucher, members of the U.S. House of Representatives Committee on Science, Space, and Technology, visited the Bureau to be briefed on ongoing oil and gas recovery research. Pictured from left to right are Congressman J. J. (Jake) Pickle, Congressman Jim Chapman, UT President William H. Cunningham, Congressman Frederick C. Boucher, and Bureau Director William L. Fisher.

Secondary Gas Recovery Project Under Way

The Bureau, in cooperation with the Gas Research Institute (GRI), has been named the project manager of a major research program designed to maximize the recovery of natural gas. The program is being undertaken by the Bureau, GRI, the U.S. Department of Energy, and the Texas natural gas industry. The goal is to develop and demonstrate technologies with near-term potential for producers to improve identification and production of unrecovered natural gas resources in known fields. Methodologies developed will have nationwide implications for the increased efficiency of natural gas production.

Geoscience Institute for Oil and Gas Recovery Research Established

The University of Texas at Austin established the Geoscience Institute to coordinate a national consortium for oil and gas recovery research. The Institute is directed by Marcus E. Milling, Associate Director of the Bureau. The first priority of the Institute is to coordinate and develop a national research plan for oil and gas recovery. The U.S. Department of Energy provided $500,000 for development of the program plan, which was submitted to DOE for review this fall.

The Institute's objective is development of an integrated broad-based, but centrally focused, research consortium aimed at increased understanding of technology required for improved oil and gas recovery. The consortium will provide a forum for addressing the private and public sectors' interest in collaborative oil and gas recovery research. Technology transfer, testing, and application of new concepts and improved techniques will be provided through cooperative programs with the private sector. Future Federal appropriations for funding the Institute program will be matched by State and private industry sources.

In addition to The University of Texas at Austin, other schools and states are part of the consortium. The members, which represent all the petroleum-producing regions of the country, are the University of Alabama, the University of Alaska, the Colorado School of Mines, the University of Houston, Illinois State Geological Survey, the University of Kansas, the University of Kentucky, Louisiana State University, the University of Michigan, Mississippi State University, New Mexico Institute of Mining and Technology, the State of North Dakota, the University of Oklahoma, Pennsylvania State University, the University of Southern California, Stanford University, Texas A&M University, the University of Tulsa, West Virginia Geological and Economic Survey, and the University of Wyoming.

Applied Geodynamics Laboratory Created

The Bureau established an Applied Geodynamics Laboratory (AGL) for scale modeling of tectonic processes for improved interpretation of complex structural traps. The laboratory, directed by Martin P. A. Jackson in cooperation with John G. Sclater, will be equipped for both physical and mathematical modeling. The nucleus of AGL is a high-speed, high-capacity centrifuge for modeling a variety of tectonic processes in which gravity plays a significant role. The centrifuge provides a body force thousands of times greater than that of gravity, thereby shortening the time necessary for experiments. AGL also will be equipped for measuring the viscosity, shear strength, and density of model materials, and for constructing, sectioning, and photographing the models. The initial research program will center on predicting the location, origin, and evolution of hydrocarbon structural traps formed around a wide variety of salt structures. The research is funded by a consortium of oil companies.

U.S. Geological Survey Cluster Meeting Hosted by Bureau

The Bureau cohosted, with the U.S. Geological Survey (USGS), the Central Region Cluster Meeting of USGS geologists and state geologists. Major agenda topics included the national geologic mapping effort, low-level radioactive waste repository site investigations, research into estimates of oil and gas reserves, desktop publishing, Mississippi River transport of sediments bearing toxins, USGS grants and contracts, and evolution of sedimentary basins.

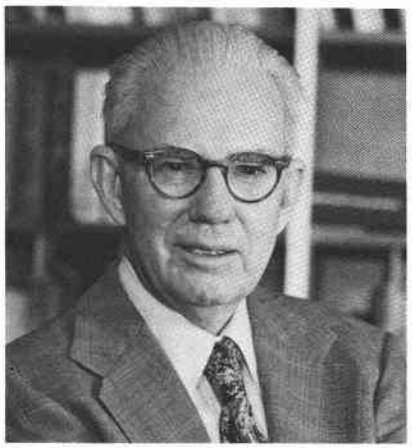
Finley and Milling Named Associate Directors

Robert J. Finley and Marcus E. Milling have been named Associate Directors of the Bureau. Finley will coordinate the Bureau's programs in oil and gas research. Milling, in addition to directing the new Geoscience Institute, will coordinate research programs in land and marine resources and environmental and mineral resources.

Awards and Honors

Virgil E. Barnes was named Distinguished Texas Scientist of the year by the Texas Academy of Science. The award recognizes exceptional achievement in a scientific specialty. Barnes accepted the award at the Academy's 91st Annual Meeting held in March at East Texas State University. Barnes has been a member of the Bureau staff since 1935. He is also a Professor Emeritus of the Department of Geological Sciences and Associate Curator of meteorites and tektites at the Texas Memorial Museum.

Barnes also learned this year that he was chosen to receive the Barringer Award at the 1989 meeting of the Meteoritical Society to be held in Vienna, Austria.



The Barringer Award, created in memory of Daniel Moreau Barringer (1859-1929) in honor of his pioneering work in the field of meteoritics, recognizes outstanding work in the field of terrestrial impact cratering and work that has led to a better understanding of impact phenomena. Barnes was informed of the honor while attending the Annual Meeting of the Meteoritical Society held in July in Fayetteville, Arkansas, where he presented a paper titled "Multi-Component Source Material for Muong Nong-Type Bediasite 30775-2."

Barnes specializes in the geology of Texas, particularly the Llano region. From 1961 to 1987, he directed the Bureau's Geologic Atlas of Texas project, which resulted in the publication of 38 large-scale geologic map sheets covering the entire state. He is known internationally for his study of tektites, glass objects found in five strewn-fields around the world. The mineral virgilite was named in his honor in 1978.

Shirley P. Dutton received the A. I. Levorsen Memorial Award, as well as the First Place Best Paper Award, at the Annual Meeting of the Gulf Coast Association of Geological Societies (GCAGS) in New Orleans for a paper she presented at the 1987 GCAGS convention. **Robert J. Finley** and **Karen L. Herrington** are coauthors of the paper, "Organic Geochemistry of the Lower Cretaceous Travis Peak Formation, East Texas Basin." The Levorsen Award is given for "the best paper with particular emphasis on creative thinking toward new ideas in exploration." This is the second year in a row that Dutton has won both awards.

Charles Kerans received the Best Paper award from the Permian Basin Section of the Society of Economic Paleontologists and Mineralogists for a paper he presented to the Permian Basin Section at a meeting in Midland, "Karst History and Dolomitization of Ellenburger Reservoirs." Another paper by Kerans, "Origin of Reservoir Compartmentalization in Lower Ordovician Karstic Dolostones, Ellenburger Group, West Texas," which he presented at the Annual Meeting of the American Association of Petroleum Geologists in Houston, was chosen to be presented at the "Best of AAPG for SPE" session of the national meeting of the Society of Petroleum Engineers, also held in Houston. Also selected for presentation at the "Best of AAPG for SPE" session was a paper by **Noel Tyler** and **Robert J. Finley**, "Reservoir Architecture: A Critical Element in the Extended Conventional Recovery of Oil."

William L. Fisher, Director of the Bureau, was appointed to the White House Science Council and the National Petroleum Council. He was also selected Co-Chairman of the Board on Earth Sciences and Resources of the National Research Council/National Academy of Sciences. In addition, Fisher was named a charter member of the 16-member Governor's Energy Council for the State of Texas.

President Ronald Reagan commends Bureau Director William L. Fisher on his service on the White House Science Council.

Martin P. A. Jackson was appointed an Associate Editor of the Geological Society of America *Bulletin* for a three-year term. He was also appointed a Member of the International Union of Geological Sciences Commission on Tectonics and Subcommission on Rheology of Rocks.

Alan R. Dutton has been appointed Technical Chairman of the Hydrogeology program of the 1990 Annual Meeting of the Geological Society of America. He was also selected to serve a three-year term (1988-90) on the Editorial Board of *Ground Water*, the research journal of the Association of Ground Water Scientists and Engineers.

New Staff

Robert L. Folk and **John G. Sclater** were appointed to the Bureau staff as Senior Research Scientists. Folk, who recently retired from active teaching, is the Dave P. Carlton Professor Emeritus in the Department of Geological Sciences. He will conduct research on carbonate petrography. Sclater holds the Shell Companies Foundation Distinguished Chair in Geophysics in the Department of Geological Sciences and is the Deputy Director of the Institute for Geophysics at The University of Texas at Austin. He will work with Martin P. A. Jackson in the Bureau's new Applied Geodynamics Laboratory.

Robert L. Folk

Dennis R. Kerr, Research Associate, joined the Bureau in April to work on the Co-production project. His initial responsibilities involved reservoir-scale facies modeling to assess co-production potential in Miocene rocks of the Gulf Coast. Kerr received a bachelor's degree in geology from California State University at Fresno. He earned a master's degree in geology at San Diego State University and was recently awarded a doctoral degree from the University of Wisconsin at Madison. His dissertation concerned the sedimentology and stratigraphy of Pennsylvanian-Early Permian strata in north-central Wyoming.

Price Named State Geologist of Nevada

Jonathan G. Price left the Bureau in September to become the new Director/State Geologist of the Nevada Bureau of Mines and Geology. The Nevada Survey, which is part of the University of Nevada at Reno, is involved in research on mineral resources and environmental geology, including urban studies and nuclear waste isolation. Price had been with the Bureau more than 7 years, mostly researching ore deposits and igneous rocks in far West Texas. Price is the second Bureau scientist to assume the duties of State Geologist in another state. Charles G. (Chip) Groat left the Bureau in 1976 to direct the Louisiana Geological Survey.

Research Staff Publications and Activities

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Lectures and Public Addresses

William A. Ambrose

"Facies analysis of fluvial Frio reservoirs, La Gloria field, Texas": presented to the Petroleum and Minerals Division, General Land Office, Austin, Texas.

Walter B. Ayers, Jr.

"Geologic controls on occurrence and producibility of coalbed methane in the Fruitland Formation (Upper Cretaceous), North Central San Juan Basin, New Mexico": presented to Southern Ute Indian Tribes, the U.S. Geological Survey, and the Gas Research Institute, Coalbed Methane Resource Symposium, Durango, Colorado.

"Geologic evaluation of critical production parameters for coalbed methane in the San Juan Basin": presented to the Gas Research Institute, Natural Gas Supply Project Advisors Group, Durango, Colorado.

"Recognition of lacustrine depositional systems in regional subsurface studies": presented to The University of Texas at Austin, Department of Geological Sciences, (Geology 383), Austin, Texas.

Virgil E. Barnes

"The origin of tektites": presented to the Texas Academy of Sciences, annual meeting, Commerce, Texas.

Robert W. Baumgardner, Jr.

"Collapse of Wink Sink, 1980": presented to Permian Basin Section, Society of Economic Paleontologists and Mineralogists, Midland, Texas.

Regina M. Capuano

"Hydrogeologic constraints on fluid-mineral equilibria in geopressured reservoirs": presented to The University of Texas at Austin, Department of Petroleum Engineering, Austin, Texas.

"Potential for biodegradation of injected wastes in the deep subsurface": presented to Texas Water Commission, Underground Injection Control Workshop, Austin, Texas.

Alan R. Dutton

"Distribution of NaCl and CaCl brines in the Southern Great Plains (USA) ground-water flow system and displacement of connate water": presented to Geological Society of America, 1988 Centennial Celebration, Denver, Colorado.

"Distribution of NaCl and CaCl brines in the Southern Great Plains ground-water flow system: hydrologic and geochemical interpretation": presented to Texas A&M University, Department of Geology, College Station, Texas.

"Natural dissolution of bedded salt by circulating ground water—Texas Panhandle": presented to the Solution Mining Research Institute, fall meeting, Dallas, Texas.

Shirley P. Dutton

"Bureau of Economic Geology studies on the Travis Peak (Hosston) Formation, East Texas": presented to the Gas Research Institute, Tight Gas Sands Project, Board of Advisors Meeting, Shreveport, Louisiana.

"Depositional and diagenetic controls on permeability distribution in the Lower Cretaceous Travis Peak Formation, East Texas": presented to The University of Texas at Austin, Department of Geological Sciences Soft Rock Seminar, Austin, Texas.

"Diagenesis of the Travis Peak Formation, East Texas": presented to the Shell Oil Company Research Laboratory, Bellaire, Texas.

Robert J. Finley

"An assessment of the natural gas resource base of the U.S.": industry briefing with Office of Policy, Planning, and Analysis, U.S. Department of Energy, Denver, Colorado, and Houston, Texas.

"An assessment of U.S. natural gas resources": presented as part of a panel on Government View of Gas Supply at the American Gas Association, Washington Representatives Third Annual Issues Conference, Point Clear, Alabama.

"Gas availability—long range": presented to Gulf Coast Cogeneration Association, fall regional conference, Austin, Texas.

"Gas reserves growth: an overlooked bonanza?": presented to the Electric Power Research Institute, Annual Fuel Supply Seminar, Kansas City, Missouri.

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

"Importance of extended reserve growth in gas resource estimates": presented to the Potential Gas Committee, annual meeting, Phoenix, Arizona.

"Natural gas markets": panel discussion presented as part of the International Association of Energy Economists, Tenth Annual North American Meeting, Houston, Texas.

William L. Fisher

"Analysis of U.S. domestic natural gas resources and supplies": presented to public affairs luncheon, Texas Independent Producers and Royalty Owners Association, Dallas, Texas.

"An assessment of the natural gas resource base of the U.S.": press briefing with Secretary of Energy, U.S. Department of Energy, Washington, D.C.

"Availability of North American natural gas—resources and deliverability": presented to Energy Forum, City College of New York, New York.

"Beyond the symmetrical life cycle": Berg Distinguished Lecture, presented to Wichita State University and Kansas Geological Society, Wichita, Kansas.

"The coming U.S. energy predicament": presented to Offshore Oil Scouts Association, New Orleans, Louisiana.

"Critical geoscience strategies in oil and gas recovery": presented to Geoscience Institute Regional Forum, St. Louis, Missouri.

"Cycles in oil prices and concerns": presented to West Austin Rotary Club, Austin, Texas.

"The future of petroleum geoscience": presented to Colorado School of Mines, Golden, Colorado.

"Manpower in the geological sciences—some ominous trends": presented to American Association of Petroleum Geologists, annual meeting, Houston, Texas.

"Natural gas as a long-term energy resource": presented to National Clean Air Symposium, Washington, D.C.

"Natural gas potential supplies and future demand": presented to Society of Independent Professional Earth Scientists, Dallas, Texas.

"Natural gas reserves and public policy": presented to Texas Society of Certified Public Accountants, Oil and Gas Conference, Houston, Texas.

"Natural gas resources, supplies, and deliverability": presented to Natural Gas Conference, University of Houston, Houston, Texas.

"Natural gas supplies—resources to deliverability": presented to American Cogeneration Association, annual meeting, Chicago, Illinois.

"Oil and gas research initiatives": Interstate Oil Compact Commission briefing to U.S. Senate, Washington, D.C.

"Oil and gas research—some challenges for the public sector": presented to University of Kentucky, Kentucky Geological Survey Sesquicentennial Lecture Series, Lexington, Kentucky.

"The oil and gas resource base: impact on the future role of independents": presented to 21st Century Committee of Independent Petroleum Association of America, Dallas, Texas.

"Oil production in Texas—future potential": presented to Travis County Bar Association, Austin, Texas.

"Opportunities in the geological sciences . . . where next?": opening session, Gulf Coast Association of Geological Societies, annual meeting, New Orleans, Louisiana.

"Outlook for oil and gas": presented to Corpus Christi Chamber of Commerce, Energy Impact Conference, Corpus Christi, Texas.

"Potential for additional oil and gas recovery in the Gulf Coast Basin": presented to Houston Geological Society, Houston, Texas.

"Prospects for oil and gas development": presented to 15th Annual Japan-Texas Conference, Austin, Texas.

"Reassessing the U.S. Oil and Gas Resource Base": presented to National Wildlife Federation, Synergy 88, Washington, D.C.

"Research technology and the changing oil and gas resource base": presented to Interstate Oil Compact Commission, Colorado Springs, Colorado.

"Rethinking the oil potential of the Permian Basin": presented to Permian Basin Petroleum Association, annual meeting, Midland, Texas.

"Scientific drilling and hydrocarbon resources": National Academy of Sciences briefing for Federal agencies, Washington, D.C.

"Secondary gas recovery research": Special guest lecture presented to Morgantown Energy Technology Center, Morgantown, West Virginia.

"The technological dependency of the U.S. oil and gas resource base": presented to Society of Petroleum Engineers, Economic Symposium, Washington, D.C.

"The U.S. oil and gas resource base: policies to realize or to forfeit?": presented to DRI Spring Energy Conference, Houston, Texas.

Graham E. Fogg

"Detailed mapping of permeability in non-vuggy dolomites with geophysical and petrophysical information": presented to Geological Society of America, annual meeting, Denver, Colorado.

"Stochastic characterization of reservoir heterogeneity on University of Texas Lands": presented to ARCO Oil and Gas Company, Plano, Texas, as part of Industrial Associates program.

Robert L. Folk

"Internal architecture of quartz": presented to Geological Society of America, 1988 Centennial Celebration, Denver, Colorado.

Thomas C. Gustavson

"Salt dissolution in the Palo Duro Basin": presented to Shell, Inc., Michigan Basin exploration group, Turkey, Texas.

H. Scott Hamlin

"Geology of the Pleasant Bayou geopressured-geothermal site and recent research efforts": presented to the U.S. Department of Energy/EG&G project managers, Austin, Texas.

"Hydrocarbon production and potential of the distal Frio Formation, Texas Gulf Coast and offshore": presented to the Petroleum and Minerals Division, General Land Office, Austin, Texas.

Christopher D. Henry

"Extensive silicic volcanic rocks of Trans-Pecos Texas": presented to National Aeronautics and Space Administration and to Jet Propulsion Laboratory, California Institute of Technology, workshop, Pasadena, California.

Susan D. Hovorka

"Marine-nonmarine evaporites": presented to Geological Society of America, Penrose Conference, Detroit, Michigan.

Martin P. A. Jackson

"Dynamic modeling of salt diapirism": presented to The University of Texas at Austin, Department of Geological Sciences, (Geology 394), Austin, Texas.

"The rise of salt domes": presented to Austin Science Academy, Austin, Texas.

Charles Kerans

"Geologic reservoir heterogeneity and oil reserve growth potential": presented to Society of Petroleum Engineers, Westside Study Group, seminar, Houston, Texas.

"Karst-controlled reservoir heterogeneity in Ellenburger Group carbonates of West Texas": presented to Society of Petroleum Engineers, annual meeting, Houston, Texas.

"Karst-controlled reservoir heterogeneity in Lower Ordovician Ellenburger reservoirs of West Texas": presented to North Texas Geological Society, Wichita Falls, Texas, and at SIPES luncheon, San Antonio, Texas.

"Karst history and dolomitization of Ellenburger reservoirs": presented to Permian Basin Section, Society of Economic Paleontologists and Mineralogists, Midland, Texas.

"Origin of reservoir compartments in Lower Ordovician dolostones, Ellenburger Group, West Texas": presented to Petroleum and Minerals Division, General Land Office, Austin, Texas.

David W. Koppenaal

"A comparison of He and Ar ICP ion sources for ICP-MS: vapor generation and solution sample introduction": presented to 1st International Conference on Plasma Source Mass Spectrometry, University of Durham, Durham, England.

Elisabeth C. Kosters

"Major onshore gas reservoirs of Texas": presented to Petroleum and Minerals Division, General Land Office, Austin, Texas.

Charles W. Kreitler

"The Diablo Plateau/Salt Flat setting, Trans-Pecos Texas: a new perspective on arid hydrogeology": presented to Chihuahuan Desert Research Institute, Third Symposium on Resources of the Chihuahuan Desert: United States and Mexico, Alpine, Texas.

"Hydrogeology of the Edwards aquifer, Barton Springs pool, as it relates to the hydrogeology of the Edwards aquifer in the San Antonio region": presented at Trinity University, Edwards Water Resources Symposium, San Antonio, Texas.

"Hydrogeology of the Frio Formation as it relates to deep-well injection of chemical waste": presented at Robert S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, monthly research colloquium, Ada, Oklahoma.

"Hydrogeology of the saline section of the Frio Formation as it relates to the deep-well injection of chemical waste": presented at Robert S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, annual review meeting, Oklahoma City, Oklahoma.

"Integrated hydrologic-geochemical-geologic studies for characterization of low-permeability settings": presented to Association of Ground Water Scientists and Engineers, Symposium on Low-Permeability Hydrogeologic Studies, Las Vegas, Nevada.

"Nitrate in Texas' ground water: distribution and identification of sources": presented at 22nd Water for Texas Conference, League City, Texas.

"Siting a low-level radioactive waste disposal facility in Trans-Pecos Texas (USA)": presented to International Association of Hydrogeologists, Orleans, France.

"Wellhead protection strategies for confined aquifer settings": presented to U.S. Environmental Protection Agency, Wellhead Protection Conference, New Orleans, Louisiana.

Stephen E. Laubach

"Coring-induced fractures: indicators of hydraulic fracture propagation in a naturally fractured reservoir": presented to Society of Petroleum Engineers, annual meeting, Houston, Texas.

"Cretaceous and Tertiary compressional tectonics as the cause of the Sabine Arch": presented to Gulf Coast Association of Geological Societies, annual meeting, New Orleans, Louisiana.

"Fracture detection in low-permeability reservoir sandstone: a comparison between BHTV and FMS logs and core": presented to Society of Petroleum Engineers, annual meeting, Houston, Texas.

"Fractured reservoirs": presented to Department of Geological Sciences, The University of Texas at Austin, graduate class in reservoir analysis, Austin, Texas.

"Geological overview of Staged Field Experiment No. 2": presented at Forum on the Relationship between Rock Mechanical Properties and Acoustic Well Log Data, Lakeway, Texas.

"Kinematics and structural style of thrust faults in western Arizona": presented at the Workshop on the California-Arizona Crustal Transect, sponsored by the U.S. Geological Survey, Flagstaff, Arizona.

"Natural fracture history of the Travis Peak Formation, East Texas": seminar presented to Texas A&M University, Center for Tectonophysics, College Station, Texas.

F. Jerry Lucia

"Carbonate reservoir geology": presented to University of Houston Petroleum Engineering Series, Houston, Texas.

"Geologic characterization of the Dune field, University Lands, Crane County, Texas": presented to Texas A&M University, technical session, College Station, Texas.

"The University's role in carbonate reservoir geology and petroleum reserve growth": presented to University of Montana at Missoula, Geology Department, Missoula, Montana.

Richard P. Major

"Cathodoluminescence and marine diagenesis in magnesian calcite" (annual Lester W. Strock Lecture in Geochemistry and Geology): presented to Skidmore College, Saratoga Springs, New York.

"Core workshop, Grayburg reservoir, Dune field, Crane County" presented to The University of Texas at Austin, Department of Geological Sciences, (Geology 391), Austin, Texas.

"Oil and gas resources—University Lands": presented to Petroleum and Minerals Division, General Land Office, Austin, Texas.

"Oil production trends in the U.S. and Texas and the role of development geology in oil reserve growth": presented to Kiwanis Club, Austin, Texas.

"Primary marine cathodoluminescence and marine recrystallization in magnesian calcite": presented at Royal Dutch Shell Exploration and Production Laboratory, Rijswijk, The Netherlands.

"Reservoir characterization, East Penwell field, San Andres Unit, University Lands, West Texas": presented to The University of Texas at Austin, Department of Geological Sciences, (Geology 391), Austin, Texas.

"The role of sedimentologists in petroleum exploration and production": presented to Austin Science Academy, Austin, Texas.

"San Andres and Grayburg reservoirs, Central Basin Platform, Permian Basin, West Texas": presented to The University of Texas at Austin, Department of Geological Sciences, (Geology 330K), Austin, Texas.

Mary W. McBride

"Romancing the (crushed) stone": presented to Central Texas Section, American Institute of Mining, Metallurgical, and Petroleum Engineers, Austin, Texas, and to Petroleum and Minerals Division, General Land Office, Austin, Texas.

Marcus E. Milling

"Application of stratigraphic sequence models in establishing field reservoir frameworks": presented to Conoco, Austin, Texas.

"Career highlights of a teacher, scientist, and scholar": keynote speech presented at retirement banquet for Professor S. D. Tuttle, University of Iowa, Iowa City, Iowa.

"Establishment of the Applied Geodynamics Laboratory—plans for hydrocarbon trap modeling prediction": presented to Amoco, ARCO, Exxon, Mobil, Maxus, Shell, Standard, Tenneco, and Texaco at various locations.

"Exploration potential of deep-water depositional submarine fan systems": presented to Lafayette Geological Society, Lafayette, Louisiana.

"Geoscience Institute program elements for comprehensive oil and gas research activities": presented to American Institute of Professional Geologists, Lexington, Kentucky.

"Geoscience Institute's oil and gas recovery research objectives": presented to American Institute of Petroleum Geologists, Kentucky chapter, Lexington, Kentucky.

"New geoscience oil and gas recovery research initiative": presented to American Institute of Petroleum Geologists, Tulsa, Oklahoma; Geological Sciences Foundation Board Meeting and Petroleum Engineers Advisors Meeting, Austin, Texas.

"Overview of exploration research trends": presented to Marathon Technology Management, Austin, Texas.

"Plans for the Geoscience Institute's oil and gas recovery research initiative": presented to Amoco, Chevron, Conoco, Mobil, Phillips, Shell, Standard, Sun, Texaco, and Unocal at various locations and to the U.S. Geological Survey, Reston, Virginia.

"Research opportunities for geoscience oil and gas recovery research": presented to U.S. Department of Energy, Basic Energy Sciences' Engineering Research Committee, Washington, D.C.

"Seismic characteristics and recognition of submarine fan systems": presented to The University of Texas at Austin, Department of Geological Sciences, (Geology 380N), Austin, Texas.

"University of Texas' MOU oil and gas recovery annexes": presented to U.S. Department of Energy MOU Organizational Review, Mobile, Alabama.

Robert A. Morton

"Depositional and structural framework of Plio-Pleistocene series, offshore Texas": presented to exploration staff of Union Pacific Resources, Houston, Texas.

"History of erosion and its causes, Sargent Beach, Texas": presented at a symposium on "Preserving the Gulf Intracoastal Waterway" sponsored by Texas A&M University Sea Grant Program and Matagorda County Extension Service, Bay City, Texas.

"History of erosional problems and its causes at Sargent Beach": presented to Matagorda County Extension Service and U.S. Congressman Mac Sweeney's office, Symposium on the Gulf Intracoastal Waterway, Bay City, Texas.

"Plio-Pleistocene depositional systems and related hydrocarbon accumulation, Texas continental shelf": presented to The University of Texas at Austin, Department of Geological Sciences, graduate class in seismic stratigraphy, Austin, Texas.

"Regional basin framework studies, offshore Texas": presented to representatives of ARCO Research, Marathon Oil Company, Texaco, and Standard Oil, Austin, Texas; Mobil Exploration and Shell Oil Company, New Orleans, Louisiana; and to Elf Aquitaine and Standard Oil, Houston, Texas, as part of Industrial Associates program.

"Structural and stratigraphic framework of offshore Texas": presented to Mobil Oil Company and Shell Offshore Company, New Orleans, Louisiana, and to Elf Aquitaine and Standard Oil Company, Houston, Texas, as part of Industrial Associates program.

Jeffrey G. Paine

"Preliminary assessment of nonfuel minerals on the Texas Continental Shelf": presented to Minerals Management Service, U.S. Department of the Interior, New Orleans, Louisiana.

Jonathan G. Price

"Beryllium ores, REE enrichments, and cryolite rhyolite in West Texas": presented to University of Arizona, Earth Science Colloquium, Tucson, Arizona.

Jay A. Raney

"Evaluation of proposed sites for the Texas repository of low-level radioactive wastes": presented to Central Region Cluster Meeting, State Geological Surveys/U.S. Geological Survey, Austin, Texas.

Jeffrey N. Rubin

"Hydrothermal zircons and zirconium mobility, Trans-Pecos Texas": presented to The University of Texas at Austin, Department of Geological Sciences, structure/petrology seminar, Austin, Texas.

"Skarn-type ore deposits": presented to The University of Texas at Austin, Department of Geological Sciences, (Geology 391), Austin, Texas.

Steven J. Seni

"Aspects of salt domes that affect chemical waste disposal": presented to Solution Mining Research Institute, fall meeting, Dallas, Texas.

"Salt tectonics on continental slope, northern Gulf of Mexico": presented to The University of Texas at Austin, Institute for Geophysics, summer meeting of Industrial Associates program; and to Department of Geological Sciences, The University of Texas at Austin, Soft Rock Seminar, Austin, Texas.

Noel Tyler

"Additional oil recovery from heterogeneous reservoirs: the promise of reservoir characterization": keynote address about the Bureau's reservoir characterization research, Exxon in-house professional reservoir management workshop, Houston, Texas, as part of Industrial Associates program.

"Characterization of heterogeneous reservoirs": presented to the Illinois Geological Survey, Champaign, Illinois.

"Geological constraints on geopressured-geothermal production": presented to EG&G Idaho, Idaho Falls, Idaho.

"Reserve growth through characterization of heterogeneous reservoirs—examples from Texas, U.S.A.": presented to Caracas Geological Society, Caracas, Venezuela, and to Lagoven and Intevep Companies, Caracas, Venezuela.

"The remaining oil and gas resource base in the Permian Basin—a national focus for hydrocarbon recovery research": presented at the Geoscience Institute Permian Basin regional meeting, Odessa, Texas.

"Reservoir architecture: a critical element in the extended recovery of oil": presented to Society of Petroleum Engineers, annual meeting, Houston, Texas.

E. G. Wermund

"Bureau of Economic Geology interests in Laguna Madre research": presented at Workshop on Scientific Interests in Laguna Madre, sponsored by the Marine Science Institute, Port Aransas, Texas.

"The capabilities of the Bureau of Economic Geology and its Land Resources Laboratory in environmental and engineering geology": presented to U.S. Army Corps of Engineers, Southwest Division Office, Dallas, Texas.

"The geology, climate, and water circulation of the Galveston Bay System": presented to National Oceanic and Atmospheric Administration, Estuary of the Month Seminar, Washington, D.C., and to Texas Environmental Coalition, the University of Houston, Houston, Texas.

"The programs and responsibilities of the Bureau of Economic Geology": presented to Texas Natural Resources Information System, Task Force, Austin, Texas, and to Soil Survey and Land Resource Workshop, College Station, Texas.

"Texas policy for permitting pipelines from the OCS in State waters": presented to Gulf of Mexico Outer Continental Shelf Regional Technical Working Group and the Minerals Management Service, U.S. Department of the Interior, New Orleans, Louisiana.

William A. White

"Preliminary results of coastal sedimentation studies": presented to Texas Parks and Wildlife Department, Texas Water Development Board, and Texas Water Commission, Austin, Texas.

Bureau of Economic Geology Seminars

The Bureau holds in-house seminars and short courses to promote communication among scientists, to encourage guidance and peer review of Bureau research, and to foster professional development of junior staff. These lectures were given during 1988:

William A. Ambrose

"Application of facies analysis to improve gas reserve growth in fluvial Frio reservoirs, La Gloria field, South Texas"

Thomas R. Calnan

"Mollusks of the Texas inner shelf with comments on their zoogeographic affinity"

George R. Coates

"The use of 'old logs' in assessing reservoir quality, central Spraberry Trend, Midland Basin"

Richard L. Dillon

"Evaluation of slides made with new computer technology"

Kenneth M. Duncan
"Broadband network solutions for VAX and Macintosh"
"Macintosh networking using TOPS"
"Using AlisaShare"
"Using TOPS on the PC"

Kenneth M. Duncan and Janet K. Jeffery
"MASS-11 to Word file transfer using DECNet Gateway with Versa TermPro"

Alan R. Dutton
"Paleohydrology and geochemistry of Permian Basin brines"

Shirley P. Dutton
"Control on permeability distribution in the Lower Cretaceous Travis Peak Formation, East Texas"

R. Stephen Fisher
"Mineralogic and geochemical evidence for water-rock reactions in Permian evaporites: examples from Wichita and Wolfcamp strata, Palo Duro Basin, Texas Panhandle"

Edgar H. Guevara
"Dean oil reservoirs of the Midland Basin"
"Geological characterization of Spraberry oil reservoirs in the central Spraberry Trend, Midland Basin"

H. Scott Hamlin
"Lower Miocene and distal Frio depositional episodes in Texas submerged lands and offshore"

Claude R. Hocott
"Production data for reservoir characterization"

Martin P. A. Jackson
"A look ahead at the Applied Geodynamics Laboratory"

Mary L. W. Jackson
"Origins of the Sabine Uplift(s)"

Janet K. Jeffery
"Introduction to PageMaker"

Charles Kerans
"Sequence stratigraphy and facies tracts of world's best-exposed carbonate ramp, San Andres Formation, Guadalupe Mountains: implications for San Andres-Grayburg reservoir framework analysis"

Elisabeth C. Kosters
"What we have learned from the gas atlas project—Gulf Coast and East Texas reservoirs"

Stephen E. Laubach and Edgar H. Guevara
"The uses and limitations of borehole imaging logs"

F. Jerry Lucia
"The 'economics' of economic geology in the petroleum business," or "Economics defines oil and gas fields"

Robert A. Morton
"Plio-Pleistocene depositional systems and related hydrocarbon accumulation, Texas continental shelf"

William F. Mullican III
"Man-induced subsidence at salt domes in the Houston diapir province"

Elizabeth D. Orr
"Using Apple Laserwriters with MASS-11 and AlisaShare"

Jeffrey N. Rubin
"Mineralogy of beryllium deposits at Sierra Blanca, Hudspeth County"

Rainer K. Senger
"Hydrodynamics of the Palo Duro Basin, Texas Panhandle; II. The return of the cross-sectional model"

Steven J. Seni and H. Scott Hamlin
"Lower Miocene and distal Frio depositional episodes in Texas submerged lands and offshore"

Robert S. Tye
"Stratigraphy and depositional systems of the Lower Cretaceous Travis Peak Formation, East Texas Basin"

Congressional, Legislative, and Special Testimony

William L. Fisher
Testimony on FY 1989 Budget authorizations: given to U.S. House of Representatives, Committee on Science, Space, and Technology, Subcommittee on Energy Research and Development, Washington, D.C.

Testimony on FY 1989 Budget appropriations: given to U.S. House of Representatives, Committee on Appropriations, Subcommittee on Interior and Related Agencies, Washington, D.C.

Testimony to Field Hearings on status of energy production in U.S.: given to U.S. House of Representatives, Committee on Science, Space, and Technology, Subcommittee on Energy Research and Development, Marshall, Texas.

Robert A. Morton
"Erosion of Texas Beaches": given to Texas Senate, Natural Resources Committee, Austin, Texas.

Steven J. Seni
"Waste Disposal in Salt Domes": given at a Wharton County Public Hearing chaired by U.S. Congressman Mac Sweeney, Wharton, Texas.

Committee Services, Offices, and Other Professional Responsibilities

Don G. Bebout

Chairman, Foundation Trustees, Gulf Coast Section, Society of Economic Paleontologists and Mineralogists.

Co-leader of field trip, "Cretaceous of the Central Texas Area," American Association of Petroleum Geologists, annual meeting.

Co-leader of field trip, "Lower Cretaceous of Central Texas," American Association of Petroleum Geologists.

Judge, American Association of Petroleum Geologists, annual meeting.

Member, Convention Policy Committee, Society of Economic Paleontologists and Mineralogists.

Alan R. Dutton

Chairperson, Ad Hoc Committee on Hydrogeology Division exhibit, Geological Society of America, 1988 Centennial Celebration, Denver, Colorado.

Chairperson, Hydrogeology Division Technical Program, Geological Society of America, 1990 annual meeting, Dallas, Texas.

Co-leader of field trip, "Dallas-Fort Worth SSC Site Surface Tour," Superconducting Super Collider Site Selection Task Force, U.S. Department of Energy.

Member, Editorial Board, *Ground Water,* Journal of Association of Ground Water Scientists and Engineers.

Shirley P. Dutton

Chairperson, Technical Session, Geological Society of America, 1988 Centennial Celebration, Denver, Colorado.

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

Judge, American Association of Petroleum Geologists, annual meeting.

Member, Committee on Awards and Judging, Society of Economic Paleontologists and Mineralogists.

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

Member, Technical Program Committee, Society of Economic Paleontologists and Mineralogists, 1989 annual meeting.

Robert J. Finley

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

Co-chairman, "Best of AAPG for SPE," Society of Petroleum Engineers Annual Technical Conference and Exhibition, Houston, Texas.

Member, Energy Modeling Forum 9 on U.S. Natural Gas Markets, Stanford University.

Member, National Research Council Committee on Undiscovered Oil and Gas Resources, National Academy of Sciences.

Member, Panel, Gas Daily and Gas Buyers Guide, Buying Gas Reserves Conference.

Member, Publication Committee, American Association of Petroleum Geologists.

Alternate Representative, Texas Natural Resources Information System Task Force.

Co-convenor, Permian Basin Regional Technical Forum, Geoscience Institute.

William L. Fisher

Chairman, Academic Research Committee, U.S. Bureau of Mines.

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

Chairman, Committee on Hydrocarbon Research Drilling, National Research Council/National Academy of Sciences.

Chairman, Committee on the Resource Base, Governmental Affairs Committee, American Association of Petroleum Geologists.

Chairman, Energy Committee, Texas Strategic Economic Policy Commission Traditional Industries Task Force.

Chairman, Energy Task Force, Austin Chamber of Commerce.

Chairman, Faculty Review Committee, Geology Foundation, The University of Texas at Austin.

Chairman, Honors and Awards Committee, American Association of Petroleum Geologists.

Chairman, Legislative Agenda Committee, Texas Low-Level Radioactive Waste Disposal Authority.

Chairman, Nominating Committee, American Association of Petroleum Geologists.

Charter Member, Governor's Energy Council.

Co-chairman, Board on Earth Sciences and Resources, National Academy of Sciences/National Research Council.

Co-director, Natural Resources Division, Policy Research Institute, LBJ School of Public Affairs, The University of Texas at Austin.

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

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

Ex Officio Member, U.S. National Committee for the International Union of Geodesy and Geophysics, National Academy of Sciences.

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

Member, Advisory Board, Center for Geotechnology, Houston Area Research Council.

Member, Advisory Council, American Association of Petroleum Geologists.

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

Member, Advisory Council, Gas Research Institute.

Member, Advisory Council, Superconducting Super Collider High-Energy Research Facility.

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

Member, Board on Mineral and Energy Resources, National Research Council, National Academy of Sciences.

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

Member, Economic Advisory Council, Office of the Comptroller, State of Texas.

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

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

Member, Geology Advisory Group, Southern Illinois University.

Member, Geology Associates Advisory Board, University of Kansas.

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

Member, National Gas Supply Task Force, American Gas Association.

Member, National Petroleum Council.

Member, Panel on Energy Competitiveness, Energy Resources Advisory Board, U.S. Department of Energy.

Member, Policy Advisory Board, Outer Continental Shelf, U.S. Department of the Interior.

Member, Research Committee, Interstate Mining Compact Commission.

Member, Research Committee, Interstate Oil Compact Commission.

Member, Screen Panel for Lowry Medal, U.S. Department of Energy.

Member, Texas Scientific Advisory Council.

Member, Town and Gown.

Member, U.S. National Committee on Geology, National Academy of Sciences and U.S. Department of the Interior.

Member, U.S. National Committee for the World Petroleum Congress, American Petroleum Institute.

Member, White House Science Council.

State Liaison Officer, Nuclear Regulatory Commission.

Vice Chairman, Committee on Liquid Fuels Production Technologies, National Research Council/ National Academy of Engineering.

Vice President, Institutional Participation, 28th International Geological Congress, Bureau of Organizing Committee.

Graham E. Fogg

Member, Editorial Board, *Ground Water,* Journal of Association of Ground Water Scientists and Engineers.

Member, Task Committee on Groundwater Monitoring Network Design, American Society of Civil Engineers.

Chester M. Garrett, Jr.

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

Judge, American Association of Petroleum Geologists, annual meeting.

Member, Board of Directors, Gulf Coast Association of Geological Societies.

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

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

Member, Public Information Committee, American Association of Petroleum Geologists.

President, Austin Geological Society.

Thomas C. Gustavson

Chairman, Symposium on Cenozoic Lake Basins in the Southern Great Plains, Geological Society of America, South-Central Section, annual meeting, Lawrence, Kansas.

Leader of field trip, "Geomorphic and Structural Features of the Salt Dissolution Zone, Texas Panhandle," for Shell, Inc., Michigan Basin exploration group, Turkey, Texas.

Christopher D. Henry

Co-leader of field trip, "Volcanic Rocks of the Fort Davis Area, Davis Mountains," Permian Basin Section, Society of Economic Paleontologists and Mineralogists.

Member, Editorial Board, Rio Grande Rift Consortium.

Claude R. Hocott

Master of Ceremonies, SPE-DOE EOR Symposium, awards luncheon.

Martin P. A. Jackson

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

Member, International Union of Geological Sciences Commission on Tectonics.

Member, International Union of Geological Sciences Subcommission on Rheology of Rocks.

Member, National Research Council, Passive Margins Group III for Workshop on Continental Margins.

William R. Kaiser

Member, Steering Committee, Gulf Coast Lignite Consortium.

Charles Kerans

Associate Editor, *Journal of Sedimentary Petrology,* Society of Economic Paleontologists and Mineralogists.

Dennis R. Kerr

Judge, Gulf Coast Association of Geological Societies, annual meeting, New Orleans, Louisiana.

Member, Program Committee, Society of Economic Paleontologists and Mineralogists, annual meeting.

Elisabeth C. Kosters

Judge, American Association of Petroleum Geologists, annual meeting.

Participant, Department of Geology, University of Utrecht, workshop.

Charles W. Kreitler

Co-convenor of Symposium, "Deep-Well Injection of Liquid Wastes in Saline Formations," American Geophysical Union, 1988 spring meeting.

Organizer of field trip, "Yucca Mountain and the Nevada Test Site," Association of Ground Water Scientists and Engineers.

Stephen E. Laubach

Chairman, Structural Geology Session, American Geophysical Union, fall meeting, San Francisco, California.

F. Jerry Lucia

Geological Coordinator, Geoscience Institute.

Member, SPE Editorial Review Committee.

Member, SPE Reservoir Characterization Reprint Committee.

Richard P. Major

Chairman, Carbonate Research Group, Society of Economic Paleontologists and Mineralogists.

Chairman, Technical Program Committee, Austin Geological Society.

Judge, American Association of Petroleum Geologists, annual meeting.

Member, Officers Nominating Committee, Austin Geological Society.

Member, Program Committee, Society of Economic Paleontologists and Mineralogists, annual meeting.

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

Amanda R. Masterson

Member, Best Paper Award Committee, Geoscience Information Society.

Mary W. McBride

Vice President, Austin Geological Society.

Marcus E. Milling

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

Chairman, Technology Committee, Geoscience Institute.

Councilor, Geological Society of America.

Member, Advisory Board, Department of Geology, The University of Iowa.

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

Member, Committee on Geology and Public Policy, Geological Society of America.

Member, National Technical Society Board, Geological Society of America.

Vice-Chairman, Foundation Board of Trustees, American Geological Institute.

Robert A. Morton

Co-editor, Gulf Coast Section, Society of Economic Paleontologists and Mineralogists, *Proceedings* of Research Conference on Shelf Sandstones and Hydrocarbon Accumulation.

Vice-Chairman, Convention Policy Committee, Society of Economic Paleontologists and Mineralogists.

Jonathan G. Price

Member, Board of Directors, Central Texas Mining Section of the Society of Mining Engineers.

Member, Program Policy Committee, Society of Economic Geologists.

Jay A. Raney

Leader of field trip for the U.S. Department of Energy at the request of Texas Low-Level Radioactive Waste Disposal Authority.

Douglas C. Ratcliff

Chairman, Field Trip Committee, Austin Geological Society.

Member, Finance Committee, Gulf Coast Association of Geological Societies.

Member, Membership Committee, American Association of Petroleum Geologists.

Robert S. Tye

Co-leader of field trip, "Modern Deltas," American Association of Petroleum Geologists.

Judge, American Association of Petroleum Geologists, annual meeting.

Noel Tyler

Chairman, Reservoir Characterization Subcommittee, Geoscience Institute.

Co-presider, Technical Session, Development Geology, American Association of Petroleum Geologists, annual meeting.

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

Member, Technical Program Committee, Geoscience Institute.

E. G. Wermund

District Representative, Texas Section, American Institute of Professional Geologists.

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

Member, Environmental Geology Committee, American Association of Petroleum Geologists.

Member, Publications Committee, Gulf Coast Association of Geological Societies.

Moderator, panel discussion: "Natural Resources Requirements in a Geographic Information System (GIS)," Texas Land Information Network Conference, sponsored by Texas General Land Office, Texas A&M Real Estate Research Center, and Stewart Information Services Corporation.

Representative for Austin Geological Society, Executive Committee, Gulf Coast Association of Geological Societies.

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

University Teaching/ Continuing Education

Don G. Bebout

Leader of field seminar, "Cretaceous Field Seminar," American Association of Petroleum Geologists, Kerrville and Austin, Texas.

L. F. Brown, Jr.

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

Alan R. Dutton

"Unsaturated-zone hydrology": Summer field camp, The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

Robert J. Finley and Noel Tyler

"Geological characterization of heterogeneous reservoirs": presented to Petroleo Brasileiro SA.

William L. Fisher

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

William L. Fisher and Noel Tyler

"Petroleum geology: production and reexploration" (Geology 391): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

Robert L. Folk

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

William E. Galloway

"Application of geology to energy resources" (Geology 368N): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

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

"Petroleum geology and trend analysis" (Geology 330K): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

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

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

Martin P. A. Jackson and William E. Galloway

"Structural and depositional styles of Gulf Coast Cenozoic continental margins": short course presented to Houston Geological Society at American Association of Petroleum Geologists annual meeting, Houston, Texas.

F. Jerry Lucia and Noel Tyler

"Development geology": short course presented at American Association of Petroleum Geologists annual meeting, Houston, Texas.

Marcus E. Milling

"Trends in oil and gas exploration research": presented to Marathon Technology Committee, Littleton, Colorado.

Jonathan G. Price

"Seminar in geochemical modeling" (Geology 391): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

John G. Sclater

"Geology of engineering" (Geology 312K): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

"Advanced seminar in geophysics and marine geology" (Geology 391): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

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

Support Staff

Administrative/Secretarial

The Administrative/Secretarial staff is responsible for the general administration of the Bureau, including personnel matters, accounting, publication sales, the reception area and switchboard, and other administrative duties such as preparation of correspondence. The Bureau's involvement in many different contracts and research projects requires the Administrative/Secretarial staff to process more than 3,000 appointment forms per year to properly allocate staff time among funding sources. In addition, this group prepares more than 6,000 individual items of correspondence each year, initiates and controls more than $4,000,000 in purchases and subcontracts, and handles publication sales in excess of $100,000 per year. Bettye A. Blitch, Executive Assistant, supervises this section.

Computer Resources

The Computer Resources staff provides three types of services to research, administrative, and support personnel: system services (facilities and hardware, operations and software), user education and consulting, and systems analysis and programming. Educational services included conducting classes and preparing documentation for users. The section supports programming and data base applications on Bureau computers (including the VAX 11/780 and more than 30 personal computers), the University's Cyber and IBM computers, and the Center for High Performance Computing's VAX and Cray systems.

In 1988, under the supervision of Elizabeth D. Orr, Manager of this section, the Computer Resources staff installed a new MicroVAX that will be used for three-dimensional geologic modeling. The staff also developed a computerized administrative management system for controlling accounting transactions, several large oil and gas related data base systems, and Cray programs for stochastic simulation of fluid-flow pathways in petroleum reservoirs and aquifers. In addition, this group continued to monitor and maintain all of the Bureau's computer resources, which now support more than 100 simultaneous users.

Publications

The Publications section was reorganized in 1988 to combine areas that work most closely together in the preparation of Bureau printed material. The design and word processing staffs were merged with editing and proofreading, under the supervision of Susann Doenges, Editor-in-Charge. In addition to these personnel changes, the section underwent a major modification in the equipment that is used to produce Bureau publications. With the installation of three personal computers linked to an office-wide network and to the Bureau's mainframe computer, the section began producing publications with desktop publishing technology. Staff received formal training in several software packages and began formatting pages electronically.

The Publications staff is responsible for editing and proofreading manuscripts and producing camera-ready copy for Bureau publications and contract reports. Many in-house documents as well as papers and abstracts submitted to professional journals by Bureau scientists also are processed by this group.

During 1988, the Bureau issued 18 new publications, 2 of which also served as final contract reports, and 22 independent contract reports. More than 16,000 pages of text were proofread, and more than 6,000 pages were edited during the year.

Quality Assurance

The Quality Assurance group, supervised by Carolyn Condon, develops and maintains the Bureau's Quality Assurance Program. The group directly supports scientific research and administrative activities by interpreting regulatory and contractual requirements and preparing and issuing Quality Assurance Procedures to ensure compliance with requirements. The staff consists of trained auditors who, in addition to preparing documents, perform reviews and evaluations of how the quality assurance program is being implemented.

During 1988, the Quality Assurance group was responsible for the preparation of the Quality Assurance Plan for low-level radioactive waste site investigation studies. Ten implementing procedures and seven specific work instructions were also issued in association with the Plan. This group also manages the Bureau's Records Center, where more than 50,000 documents are stored for future access by contracting agencies.

Cartography

The Bureau's Cartographic section has always distinguished itself by producing high-quality, full-color maps, as well as fulfilling all other Bureau drafting needs for text illustrations, slides, posters, and display materials. Under the supervision of Richard L. Dillon, Chief Cartographer, this section continued in this tradition during 1988. Five full-color maps and more than 2,500 other drafted items were produced by this group during the year.

A new IBM PC-based graphics system was installed for use by the Cartographic section in preparing slides, and 65 percent of the slides made during the year were prepared on this equipment. A Macintosh II system was purchased in mid-1988 consisting of two computers and oversized screens. Twenty-five percent of all text figures were prepared on this system.

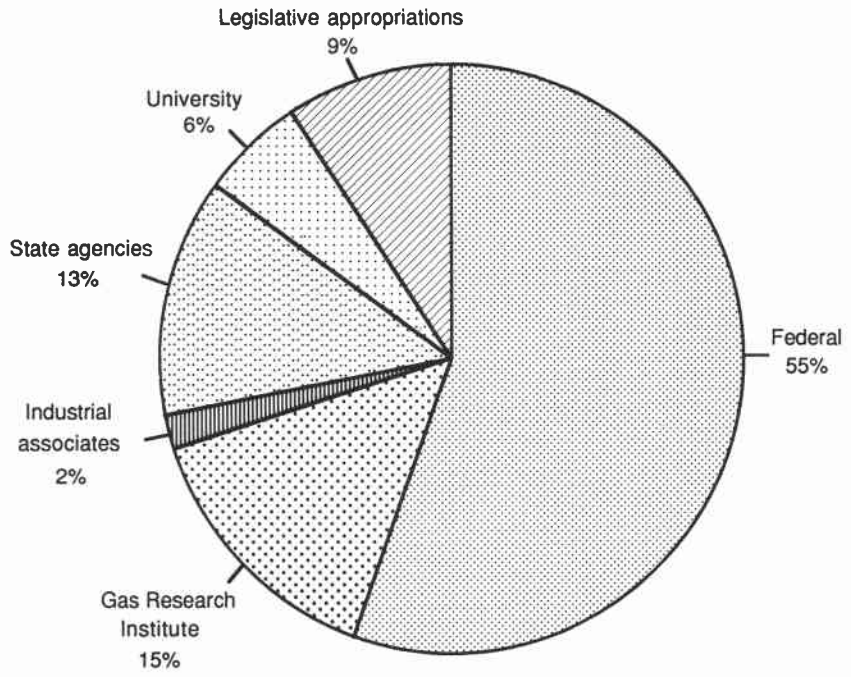
In Memoriam: Bureau Remembers Tony Walston

The Bureau lost a friend and skilled cartographer this year when Tony M. Walston passed away on May 25. Walston joined the Bureau staff in April 1985 as a Cartographic Technician II and worked exclusively on the Submerged Lands of Texas project while employed at the Bureau. The Bay City–Freeport volume of the Submerged Lands series, published in 1988, is dedicated to Walston.

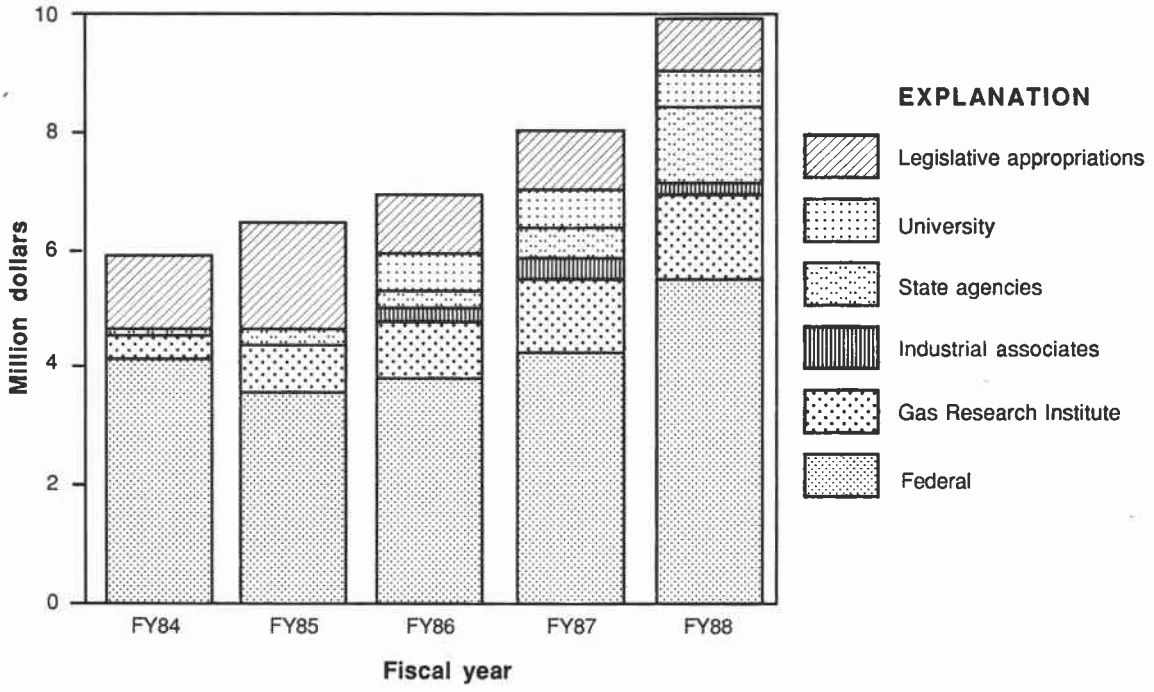
Walston grew up in East Texas and graduated from Gladewater High School. He studied geography at The University of Texas at Austin and received a bachelor's degree from UT in 1980. Before joining the Bureau staff, he was employed at the Ferguson Map Company in Houston.

Walston is remembered by his colleagues for his personal warmth, his dedication to his work, and his cartographic skills. He is missed by those who knew and worked with him.

FY88 SOURCES OF FUNDING



FIVE-YEAR BUDGET TRENDS



Bureau of Economic Geology

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Dr. Edward C. Bingler, Deputy Director (on leave)

Dr. Robert J. Finley, Acting Deputy Director

Douglas C. Ratcliff, Associate Director for Administration

Bettye A. Blitch, Executive Assistant

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Environmental Resources
Dr. Shirley P. Dutton *(Acting)*
Gas Resources
Dr. Marcus E. Milling
Geoscience Institute for Oil and Gas Recovery Research
Dr. Jonathan G. Price
Mineral Resources
Dr. Noel Tyler
Oil Resources
Dr. L. F. Brown, Jr.
Technical Review and Geoscience Studies
Dr. E. G. Wermund
Land Resources

Senior Research Scientists

Dr. Virgil E. Barnes
Dr. Don G. Bebout
Dr. L. F. Brown, Jr.
Dr. Robert L. Folk
Dr. William E. Galloway
Dr. Claude R. Hocott
Dr. Martin P. A. Jackson
Dr. Robert A. Morton
Dr. John G. Sclater

Research Scientists

Dr. Jules R. DuBar
Dr. Alan R. Dutton
Dr. Shirley P. Dutton
Dr. Thomas C. Gustavson
Dr. Christopher D. Henry
Dr. William R. Kaiser
Dr. David W. Koppenaal
Dr. Charles W. Kreitler
Dr. Marcus E. Milling
Dr. Jonathan G. Price
Dr. Jay A. Raney
Dr. Stephen C. Ruppel
Dr. Zvi Sofer
Dr. Noel Tyler
Dr. E. G. Wermund

Research Associates

Dr. Walter B. Ayers, Jr.
Robert W. Baumgardner, Jr.
Dr. Regina M. Capuano
George R. Coates
Edward W. Collins
Dr. R. Stephen Fisher
Dr. Graham E. Fogg
L. Edwin Garner
Dr. Edgar H. Guevara
Dr. Charles Kerans
Dr. Dennis R. Kerr
Dr. Elisabeth C. Kosters
Dr. Stephen E. Laubach
Dr. Richard P. Major
Dr. Stephen J. Martel
Dr. Mark A. Miller
Dr. Bridget R. Scanlon
Steven J. Seni
Dr. Robert S. Tye
William A. White

Research Scientist Associates

M. Saleem Akhter
William A. Ambrose
Thomas R. Calnan
S. Christopher Caran
Robert D. Conti
Chester M. Garrett, Jr.
Roselle M. Girard
H. Scott Hamlin
Tucker F. Hentz
Mark H. Holtz
Susan D. Hovorka
Jack M. Howard
Mary L. W. Jackson
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David A. Johns
Mary W. McBride
William F. Mullican III
H. Seay Nance
Jeffrey G. Paine
Bernd C. Richter
Michael P. Roberts
Jeffrey N. Rubin
Rainer K. Senger
Gary W. Vander Stoep

Senior Research Fellows

F. Jerry Lucia
Edwin B. Neitzel

Research Fellows

Dr. Amos Bein
Dr. Bernard P. Célérier

Administrative Staff

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Lynda A. Miller
Anke Rommerskirch
Diane C. Ruetz
G. Steven Stubbs
Pamela M. Trice
Peggy J. Trunnell
Virginia C. Zeikus

Publications

Susann V. Doenges
Editor-in-Charge
Lana S. Dieterich
C. Duran Dodson
Bobby S. Duncan
Margaret L. Evans
Chief Designer
Michelle C. Gilson
Diane Callis Hall
Jamie S. Haynes
Lola E. Huitt
Mary Ellen Johansen
Dorothy C. Johnson
Kurt E. Johnson
Susan J. Lloyd
Amanda R. Masterson
Melissa Snell
Maris V. Strautmanis
Rebecca Y. Tovar

Computing Staff

Elizabeth D. Orr
Manager
Kenneth M. Duncan
Richard D. Edson, Jr.
Bradley E. Garton
Janet K. Jeffery
Diane M. Spinney
W. Gerald White

Mineral Studies Laboratory

Steven W. Tweedy
Acting Chief Chemist
Christopher C. Lewis
Sharon G. Lowe
Thomas L. Pinkston
Leslie F. Quinton

Core Research Center

Allan R. Standen
Curator
Jon D. Boldovici
Ronald P. Brock
George T. Bush
Mary A. Cundieff
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