1989

Annual Report

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

Foreword

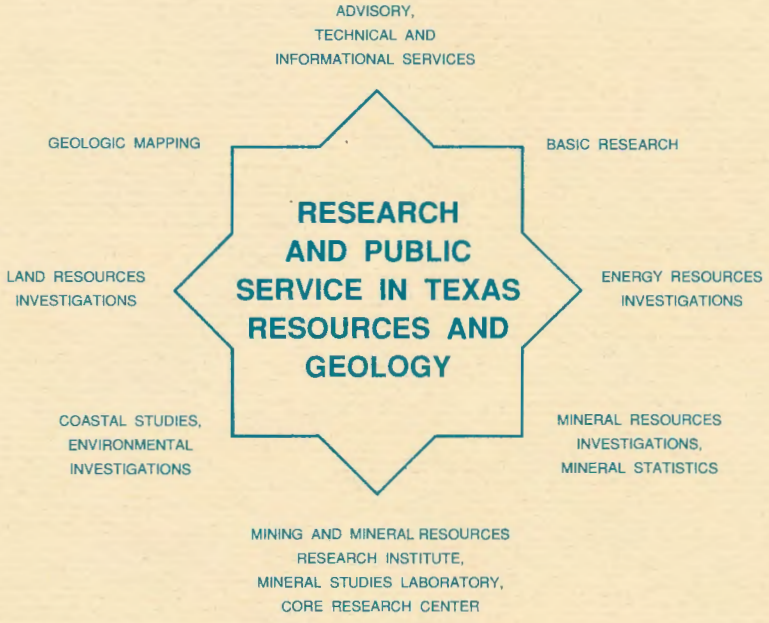
The Bureau of Economic Geology, established in 1909 as the successor to the Texas Geological Survey and the Texas Mineral Survey, is a research entity of The University of Texas at Austin. It also functions as the State Geological Survey, a quasi-State agency, and the Bureau Director represents Texas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

The Bureau of Economic Geology, now celebrating its 80th year as a geoscience research institution, has steadily grown to become one of largest state geological agencies in the United States. This growth is dramatically represented by the numerous projects conducted in 1989, covering a wide range of research topics funded from a variety of sources. By all measures, 1989 was one of the most vigorous and dynamic years in the Bureau's history, with an operating budget of $10 million and a total of 51 ongoing research projects. Of these 51 projects, 11 were initiated in 1989, notably:

(1) the State Lands Energy Resource Optimization (SLERO) Center, managed by the Bureau and composed of a consortium of Texas state universities to research development of improved strategies for petroleum recovery from State Lands;

(2) the National Gas Atlas, funded by the Gas Research Institute to synthesize data on major gas reservoirs of the central and eastern Gulf Coast and Midcontinent regions of the U.S.; and

(3) four reservoir characterization projects that involve study of outcrop and modern-environment, reservoir-scale facies assemblages and their petrophysical properties to help detail the architecture of flow-unit heterogeneities in analogous subsurface petroleum reservoirs.

In addition, Bureau scientists received funding in 1989 for four research topics after submission of proposals to the highly competitive Texas Higher Education Coordinating Board's Advanced Technology and Advanced Research Programs. The year also witnessed the successful conclusion of three multiyear endeavors: (1) characterization and assessment of the petroleum potential of University Lands in the Permian Basin of West Texas; (2) compilation and publication of the last two of seven coastal atlases produced during the 14-year-long State Submerged Lands of Texas project; and (3) publication of the Gas Research Institute-funded *Atlas of Major Texas Gas Reservoirs*.

As in all years since the early 1980's, energy resource investigations dominated the Bureau's research efforts in 1989. The Geoscience Institute for Oil and Gas Research, housed at the Bureau and comprising a national consortium of research agencies, is pursuing methods for developing advanced hydrocarbon-recovery technology. Now in its second year, the Geoscience Institute has firmly established its administrative base and is actively pursuing the funding needed for its myriad research programs. In 1989 regional genetic-stratigraphy studies received increased emphasis in hydrocarbon-related Bureau projects funded largely by industry sources. These projects include continuing seismic and stratigraphic investigations of upper Tertiary and lower Quaternary depositional systems of the northwestern Gulf of Mexico and Texas continental shelf, sequence-stratigraphic analysis of offshore South African and Taiwanese basins, and characterization of major Permian Basin reservoirs. An analysis of upper Paleozoic cyclothemic successions of the Eastern Shelf and adjacent Midland Basin, based on Bureau research conducted over more than 15 years, will culminate in an expanded Bureau report in which the latest sequence-stratigraphic concepts are integrated with more traditional subsurface correlations and mapping. Reflecting another shift of research focus, Bureau reservoir characterization studies increasingly integrated outcrop analysis of reservoir facies with subsurface data. Exposed facies displaying internal lithologic baffles (flow barriers) that are typical of partially drained, compartmentalized oil reservoirs provide a clearer perspective of the complex but resolvable heterogeneities of these reservoirs.

Enhanced gas recovery from low-permeability (tight) sandstone reservoirs is currently an outstanding challenge to the U.S. natural gas industry. A 7-year Bureau program sponsored by the Gas Research Institute continues to investigate factors controlling porosity and permeability, fracture distribution, and state of stress in low-permeability gas reservoirs. Such knowledge will help improve completion techniques and increase recoveries from these notoriously miserly but high-potential reservoirs. This program was expanded this year to include characterization of the Frontier Formation in the Green River Basin, Wyoming, and the Cleveland Formation in the Anadarko Basin, Texas Panhandle. Stratigraphic, structural, and petrographic data on the gas-bearing Travis Peak Formation of East Texas, the primary focus of previous years, are being integrated and synthesized for final publication. "Secondary Natural Gas Recovery: Targeted Technology Applications for Infield Reserves Growth," a 3-year research program funded by the Gas Research Institute, also tackles the vexing problem of how to extract the vast quantities of as yet unrecovered conventional natural gas resources remaining in many gas-prone U.S. basins. In 1989 component studies focused on heterogeneous Tertiary fluvial and deltaic sandstone reservoirs of the Gulf Coast Basin to determine the geological, petrophysical, geophysical, and engineering controls on natural gas distribution. Bureau researchers also expanded their examination of the various geologic and hydrologic

controls on coalbed methane occurrence and producibility in coal-bearing strata of the Fruitland Formation in the San Juan Basin, Colorado and New Mexico.

The Bureau's recently established experimental tectonics program effectively complements the varied energy-resource investigations. The Applied Geodynamics Laboratory (AGL), now in its second year, is funded by an industrial associates consortium and uses dynamically scaled models to duplicate specific geologic structures. Innovative experimental research conducted at the AGL during 1989 examined a range of gravity-driven tectonics involving extension, salt tectonics, and combinations of these structural styles to elucidate the location and genesis of hydrocarbon traps. In a related project of a more applied nature, the structural evolution of several different classes of salt structures is being studied using a high-density, three-dimensional seismic grid of the Green Canyon area, northern Gulf of Mexico. The "Mechanics of Segmentation along Normal Faults" project uses structural modeling experiments to determine (1) how segments of normal faults grow and join and (2) where subsidiary structures might develop along segmented normal faults. Improved understanding of these topics will lead to better prediction of sites of economic mineralization and hydrocarbon traps.

In 1989 Bureau projects also addressed a range of ground-water and environmental issues of importance to Texas and the United States. The Texas Low-Level Radioactive Waste Disposal Authority continued its sponsorship of the Bureau's geologic and hydrologic investigations of a potential waste-repository site in Hudspeth County, West Texas. Most remaining data collection and analyses were completed in late 1989. In a recently initiated program, Bureau researchers are investigating the extent and nature of subsurface degradation reactions of liquid hazardous waste disposed of by deep-well injection. Although practiced nationwide, deep-well waste injection is by far most prevalent in the Gulf Coast region. The U.S. Environmental Protection Agency continued funding for Bureau projects that are (1) examining multiple-source identification of sodium chloride contamination in ground water and (2) developing methods for well-head protection of confined aquifers nationwide. The Lower Colorado River Authority funded a program to study surface- and ground-water management strategies in Wharton and Matagorda Counties, a region of the Texas Gulf Coast undergoing residential and industrial growth.

Environmental, economic, and political issues involving Texas coastal lands continue to be of particular interest to the Texas public, especially in light of the active 1989 hurricane season along the Gulf and Atlantic coasts. With the 1989 publication of the Port Lavaca and Kingsville atlases of the seven-volume State Submerged Lands of Texas series, full-color maps of biologic and geochemical surveys of all Texas coastal lands are now available. In a closely related project funded by the Texas Parks and Wildlife Department, the Bureau is currently examining the present and historical role of fluvial sedimentation in developing and maintaining estuarine and marine habitats in selected deltaic areas of the Texas coast. Along other portions of the coast, both short- and long-term shoreline and vegetation-line changes due to natural processes and residential/industrial development were monitored during the year.

Bureau mineral-resource investigations in 1989 focused on 1:24,000-scale geologic mapping, igneous petrogenesis, ore deposition, and mineral assessment in Trans-Pecos Texas. Extensive surveys of the igneous and economic geology of the Christmas Mountains (completed) and Davis Mountains (in progress) regions of the Trans-Pecos magmatic province reveal a complex geologic history. Study of the volcanic and geochemical evolution of caldera development has helped identify areas of hydrothermal alteration and associated mineral prospects within these areas. A mineral resource assessment was conducted in the newly established Big Bend Ranch State Natural Area for the Texas Parks and Wildlife Department and the General Land Office.

Many other Bureau maps are in final phases of preparation. The new "Geologic Map of Texas" and "Tectonic Map of Texas," to be presented in full color at scales of 1:500,000 and 1:750,000, respectively, are in advanced stages of color separation. Several out-of-print maps in the Geologic Atlas of Texas series are being redrafted for final publication processing.

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, established by The University of Texas at Austin and housed at the Bureau of Economic Geology, is a national consortium composed of leading universities and other State entities with advanced oil and gas recovery research programs in petroleum engineering, geophysics, and geology. In 1989, the Institute's second year of operation, membership increased to 23 member organizations representing 18 states, covering all major hydrocarbon-producing provinces of the United States. The Institute proposes to develop a joint, nationally based, industry/university interdisciplinary recovery research program involving engineering, geological, and geophysical specialists 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.

Institute programs will be base-supported by the U.S. Department of Energy (DOE) with cost-sharing from industry, state, and university funds.

The Institute is currently under contract to the DOE's Office of Fossil Energy to assist in the identification and prioritization of research and development program requirements for an advanced, interdisciplinary recovery research initiative. The Institute submitted its three-volume program study report to DOE in February 1989. Over 500 engineers and scientists representing industry, state and federal agencies, and universities participated in development of the program study summary. The resulting program study report is the most comprehensive document of its type ever developed in the private sector.

Based on the Institute's report and other studies, it is estimated that there are over 325 billion barrels (Bbbl) of unrecovered mobile and immobile oil resources in existing reservoirs. In addition, more than 460 trillion cubic feet (Tcf) of inferred, extended, and low-permeability gas resources occurs in known reservoirs. A significant portion of these resources is currently being economically lost as wells are plugged and abandoned because of the lack of improved recovery technologies. It is estimated that upward of 100 Bbbl of mobile and immobile oil and over 300 Tcf of gas can be economically recovered from existing fields if new, improved recovery techniques are developed and applied. A better focused, public-sector geoscience oil and gas research program can play a critical role in development of cost-effective, advanced recovery technological applications to tap this existing resource. Development of improved recovery efficiency methods will provide national energy security by increasing reserves in existing reservoirs and thus reducing our dependency on foreign crude oil imports.

Principal activities of the Institute during 1989 include

- Prioritization of Research Needs
  The Institute established technical subcommittees to identify and describe research activities related to major program elements. Working in conjunction with the Institute's Technical Study Committee, the subcommittees ranked the higher priority research activities; 13 of the 24 highest priority research activities focus on reservoir heterogeneity problems. The greatest recovery research needs relate to improved description and quantification techniques to better define reservoir architecture and the controls of reservoir heterogeneity on recovery efficiency.

- Development of Interdisciplinary Program Options
  Based on prioritization and categorization of research activities, three program options were proposed:

  (1) Reservoir Heterogeneity - includes development of improved methods for (a) mapping and modeling heterogeneities, (b) scaling reservoir properties, and (c) testing advanced mobility control agents;

  (2) Reservoir Geomechanics - includes developing methods of characterizing fractured reservoirs, enhancing understanding of the structural controls on hydrocarbon distribution and fluid flow, improving induced-fracture well treatments, and devising better methods for predicting performance of fractured reservoirs; and

  (3) Rock/Fluid Interactions - includes studying the interaction of natural and injected fluids on reservoir rock properties and performance, to obtain improved understanding of mineral equilibria and

kinetics of reactions at in situ reservoir conditions for developing modeling techniques to predict reservoir quality and recovery efficiency.

- Submission of Proposals for Recovery Research Support
  In July, based on the Institute's program study, a 3-year, $24 million proposal was submitted to DOE. The proposal focused on eight regionally specific projects that address recovery efficiency needs in a variety of reservoir types. The Institute is requesting $12 million from DOE in FY90 and proposes to match that $12 million with state and industry support.

With the Geoscience Institute's organizational and administrative structure now in place, we have established a broad, national constituency for the technical and political support of the program effort.

In July Congress appropriated $5 million specifically for geoscience oil and gas recovery in FY89, and in August the Senate-House Conference Committee provided $6 million for the program in FY90. We believe that significant opportunities exist for moving the Institute's program forward in FY91 with support from Federal sources.

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

Robert A. Morton, principal investigator; assisted by Gerald F. Wick

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 2,500 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 1989 were BP Exploration, Consolidated Natural Gas, Fairfield Industries, and Halliburton Geophysical Services.

In 1989, correlation and quantitative mapping of Plio-Pleistocene stratigraphic units in the West Cameron 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.

Depositional Styles of Neogene Slope Systems, Texas Continental Shelf

Robert A. Morton, principal investigator; 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 1989 additional electric logs and paleontologic 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 prepared for each of the stratigraphic units to document depositional patterns and to identify pathways of sediment transport. In addition, a summary of the depositional history and reservoir characteristics of the middle Miocene and middle Pliocene slope sandstones was written and submitted for publication as a forthcoming Bureau Report of Investigations.

International Basin Studies

L. F. Brown, Jr., principal investigator, and Steven J. Seni (Bureau of Economic Geology); Paul Burden, Eric Jungslager, Andre Muntingh, Simon Robson, and Petrus Strauss (SOEKOR, Ltd.); Mike Chang and Andy Ting (Chinese Petroleum Corporation)

Bureau scientists supervised and participated in analyses of petroleum-bearing sedimentary basins of offshore South Africa and Taiwan as part of a cooperative international project funded mostly by SOEKOR, Ltd., of Cape Town, South Africa, and the Chinese Petroleum Corporation of Taiwan. Five geologists and geophysicists of SOEKOR, Ltd., used 10,000 km of seismic data and associated well data to examine the geology of Cretaceous strata (mid-Aptian to late Maastrichtian) in 90,000 km^2 of the Western Offshore Basin of South Africa. The basin strata were divided using sequence stratigraphy into systems tracts composing 35 depositional sequences. The ultimate goal of the study was to identify hydrocarbon plays that are associated with stratigraphic traps in lowstand systems tracts near relict shelf edges. Two related prior programs addressed the sequence stratigraphy of the Bredasdorp and Pletmos Basins off the south coast of South Africa. Results of all three studies are being integrated into SOEKOR's exploration and drilling program. Wells are now being drilled and discoveries are being made in the Bredasdorp Basin; drilling began in the Pletmos Basin in late 1989.

Two members of the professional staff of the Chinese Petroleum Corporation initiated a sequence-stratigraphic analysis of the Tainan Basin, which lies beneath the Taiwan Straits. Oligocene and lower Miocene strata were reviewed using seismic and well data. Possible upper Oligocene lowstand submarine fans were delineated and mapped. These inferred fans are of the same age as a lowstand canyon-fill gas sand discovered in early 1989. Preliminary analysis of lower Miocene strata also indicates potential reservoirs within fault blocks of Pliocene age. These studies are part of a major exploration effort in the Tainan Basin.

Geological Characterization of Reservoirs on University Lands

Noel Tyler and Don G. Bebout, principal investigators; 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, Rainer K. Senger, and Gary W. Vander Stoep; assisted by Jeffrey W. Black, Thomas L. Cogswell, Andrew P. Czebieniak, Guoqiu Gao, Matt L. McCullough, John E. Nicol, Nestor D. Phillips, Robert S. Single, and Michael A. Starcher

This is the fifth and final year of funding from the University of Texas System for study of petroleum reservoirs on University Lands. Eleven plays, listed in order of highest to lowest production, occur on University Lands: San Andres/Grayburg Platform Carbonate, Siluro-Devonian, Ellenburger, Spraberry and Dean Sandstone, Clear Fork Platform Carbonate, Queen Tidal-Flat Sandstone, Wolfcamp Carbonate, Pennsylvanian Platform Carbonate, Upper Guadalupian Platform Sandstone, Delaware Basin Submarine-Fan Sandstone, and Simpson Group Marine Sandstone.

Production from these plays is primarily from moderate to large reservoirs, those that have produced more than 1 million barrels (MMSTB) of oil. Original oil in place from these reservoirs is about 7.25 billion barrels (BSTB), and cumulative production from these same reservoirs was 1.5 BSTB through 1987. Therefore, 2.2 BSTB of mobile oil and 3.3 BSTB of residual oil remain in the reservoir. The objective of the project was to locate the remaining mobile oil on University Lands and develop methods by which more of the mobile oil could be produced.

San Andres/Grayburg Platform Carbonate Play

San Andres/Grayburg reservoirs of Permian lower Guadalupian age account for about 40 percent of the oil produced from the Permian Basin and 15 percent of all oil produced in Texas. On University Lands more than 0.5 BSTB of oil had been produced through 1987 from reservoirs that have each produced at least 1 MMSTB. Four subplays compose this play: (1) San Andres Open-Marine Platform–Central Basin Platform; (2) Grayburg Open-Marine Platform–Central Basin Platform; (3) Grayburg High-Energy Carbonates–Ozona Arch; and (4) Karsted San Andres.

The San Andres and Grayburg Open-Marine Platform–Central Basin Platform subplays are located along the eastern side of the Central Basin Platform. Of the 13 reservoirs in these subplays, 7 are in the San Andres and 6 are in the Grayburg. The depositional style and

petrophysical properties of the San Andres and Grayburg reservoirs are similar, but volumetrics of the two subplays are somewhat different. The San Andres and Grayburg reservoirs are developed in thick dolomitized subtidal facies of upward-shoaling cycles. The San Andres reservoirs had produced 139 MMSTB of oil through 1987 from University Lands, 41 percent of the total production from these seven reservoirs on all lands. The Jordan reservoir, the largest of the seven, produced 68 MMSTB; the next largest reservoirs are Penwell and Fuhrman-Mascho, which produced 28 and 27 MMSTB, respectively. Remaining mobile oil on University Lands is 269 MMSTB; of this, 55 MMSTB occurs in the Jordan reservoir and 54 MMSTB in the Fuhrman-Mascho reservoir. Results of Bureau research on Emma field are documented in Report of Investigations No. 178 (1988). Both Jordan and Penwell fields have been studied, and the final Bureau reports are being written. Grayburg reservoirs had produced 257 MMSTB oil through 1987 from University Lands, 24 percent of the total production from these six reservoirs on all lands. The largest of these reservoirs by far is McElroy, which has produced 181 MMSTB from University Lands, followed by Dune, which has produced 55 MMSTB. Of the 852 MMSTB of remaining mobile oil in these six reservoirs on University Lands, more than half (539 MMSTB) is calculated to be in the McElroy reservoir. Further information on Dune field is available in the 1987 Bureau Report of Investigations No. 168.

The Grayburg High-Energy Carbonates–Ozona Arch subplay, located on the Ozona Arch in Crockett and Reagan Counties, comprises five reservoirs. The reservoir section is more than 300 ft thick and is composed of numerous upward-shoaling carbonate cycles. Through 1987, 129 MMSTB of oil was produced from University Lands; remaining mobile oil is calculated to be 126 MMSTB, with most of this residing in Big Lake (64 MMSTB) and Farmer San Andres (36 MMSTB) reservoirs. Farmer field was examined through Bureau research, and the results will be presented in a Bureau Report of Investigations.

The Karsted San Andres subplay is located at the southern end of the Central Basin Platform, on the structurally highest portion of the platform. The University holds no interest in the giant Yates field, which occurs in this area, but it does have interest in the smaller Taylor-Link West and Crockett fields. The reservoirs are characterized by thick accumulations of reservoir-quality grainstones at the top of the upward-shallowing sequence. Permeability is increased by solution-enhanced fractures, microbreccias, and large vugs, which developed during a period of prolonged exposure and karstification. The two fields on University Lands have a total of 86 MMSTB original oil in place and an ultimate recovery of 15 MMSTB, for a recovery efficiency of 17 percent. Estimated volume of mobile oil remaining without modification of current producing methods is 20 MMSTB for Taylor-Link West field and 5 MMSTB for Crockett field. A detailed study of the Taylor-Link West reservoir is in preparation.

Siluro-Devonian Play

The Siluro-Devonian is a thick (up to 1,500 ft) sequence of predominantly carbonate rocks that occur throughout most of the Permian Basin. Twenty-one reservoirs, which have produced more than 1 MMSTB each, had original oil in place of 1.5 BSTB and cumulative production of 467 MMSTB, about one-third of the total production from University Lands. The Siluro-Devonian Carbonate play is subdivided into four subplays: (1) Fusselman Formation Shallow Platform Carbonates; (2) Wristen Formation Platform Margin Buildups and Shallow Platform Carbonates; (3) Thirtyone Formation Skeletal Packstone; and (4) Thirtyone Formation Chert. A report is now in preparation to summarize the results of the regional Siluro-Devonian research.

The Fusselman Formation Shallow Platform Carbonates subplay includes two reservoirs on University Lands. The Fusselman is composed of ooid grainstone and packstone with intergranular porosity at the base and a relatively thick interval of pelmatozoan grainstone and packstone with only local leached porosity at the top. Total cumulative production from the two reservoirs is 2.4 MMSTB; approximately 5 MMSTB of mobile oil remain in the reservoirs.

The Wristen Formation Platform Margin Buildups and Shallow Platform Carbonates subplay facies vary from buildup-related, skeletal grainstone and wackestone (both limestone and dolostone) to dolomitized shallow-water wackestones. Eight University Lands reservoirs in this subplay account for 25 percent of the total Siluro-Devonian production in West Texas and about 34 percent of the cumulative production on University Lands; remaining mobile oil on University Lands in these reservoirs totals 205 MMSTB.

The Thirtyone Formation Skeletal Packstone subplay includes five reservoirs on University Lands. This subplay contains two distinct facies: (1) skeletal packstones and grainstones and (2) spiculitic chert. Thirtyone Formation carbonate reservoirs have produced nearly 36 MMSTB, about 8 percent of the Siluro-Devonian production on University Lands. Original oil in place totals 164 MMSTB; remaining mobile oil in this subplay is estimated to be 89 MMSTB.

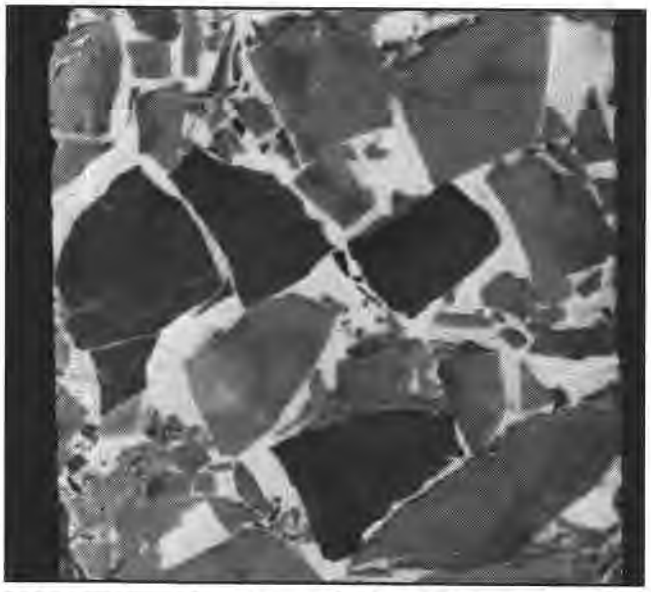
Six University Lands reservoirs are assigned to the Thirtyone Formation Chert subplay. Chert in the Thirtyone Formation accumulated in quiet, probably

deep-water conditions removed from the influx of carbonate detritus. Most of the porosity in these rocks is moldic and intercrystalline. Thirtyone Formation chert reservoirs account for more than 50 percent of the total production from the Siluro-Devonian in West Texas. On University Lands, production from these reservoirs currently totals more than 270 MMSTB and represents 58 percent of the total production from University Lands Siluro-Devonian reservoirs. Total original oil in place for the subplay is about 761 MMSTB. Remaining mobile oil on University Lands in these reservoirs is estimated to be more than 200 MMSTB. A Bureau report on the Three Bar reservoir is in preparation.

Ellenburger Play

The Ellenburger play in West Texas represents the deepest significant production in the Permian Basin. Ellenburger reservoirs are structural traps formed in thick, massive dolostones, which were deposited on an extensive restricted carbonate ramp. The Ellenburger play on University Lands consists of two subplays, (1) Karst-Modified Restricted Ramp subplay and (2) Selectively Dolomitized Ramp Carbonate subplay. Results of research on the regional distribution of the Ellenburger will be published as a Bureau Report of Investigations.

The Karst-Modified Restricted Ramp subplay in Crane and Andrews Counties includes 14 reservoirs. The carbonate platform succession of the Ellenburger has been substantially modified by pre-Middle Ordovician erosion and karstification. Reservoir heterogeneity is a function of extensive dissolution, cave formation, and subsequent infilling. Cumulative production is 204 MMSTB, or 81 percent of University Lands Ellenburger production. It is estimated that 225 MMSTB of mobile oil resides in the 14 reservoirs of this subplay. Emma field contains an estimated 68 MMSTB remaining mobile. Results of the Emma study were published in 1989 as Report of Investigations No. 186.



Solution-collapse breccia from the deep Ellenburger gas trend of the Val Verde and Delaware Basins. These rocks are similar to those of the main karsted Ellenburger oil play but most likely formed by a complex interplay of meteoric dissolution (karst), solution by basinal fluids, and fault-related brecciation.

The Selectively Dolomitized Ramp Carbonate Subplay is located in Reagan, Irion, and Crockett Counties on the southern portion of the Ellenburger ramp. The five reservoirs of this subplay have a total cumulative production of 37 MMSTB, making up 19 percent of total University Lands Ellenburger production. Reservoirs of this play are composed of mixed limestone and dolostone strata; porosity is a result of dissolution caused during late-stage burial dolomitization of the limestones. Cumulative production for the five reservoirs in this subplay ranges from 1.8 to 21 MMSTB and original oil in place values, from 7.5 to 104.7 MMSTB. Big Lake, the largest of these reservoirs, is estimated to contain 38.7 MMSTB of remaining mobile oil.

Clear Fork Platform Carbonate Play

The Clear Fork Platform Carbonate play, composed of seven reservoirs, is located in the northeastern part of the Central Basin Platform. The Clear Fork carbonates were deposited as numerous upward-shoaling cycles of shallow marine to supratidal sediments, now partially to completely dolomitized and containing sulfates as nodules and cements. Reservoirs in this play produce from low, broad anticlines, but the porous and permeable zones are laterally discontinuous. The 1987 cumulative production of the Clear Fork Platform Carbonate play was 117 MMSTB of an original 696 MMSTB of original oil in place. Nearly 346 MMSTB of mobile oil remains in these University Lands reservoirs.

Queen Tidal-Flat Sandstone Play

The Queen Tidal-Flat Sandstone play is located along the northern edge of the Delaware Basin, western and eastern edges of the Central Basin Platform, and southeastern edge of the Midland Basin. The six reservoirs of this play have a cumulative production of 65 MMSTB of oil. Queen reservoirs consist of shoreface, tidal-flat, and eolian depositional facies in upward-shoaling siliciclastic cycles. Production is from multiple sandstone beds within the reservoir section. Through 1987, 38.6 MMSTB had been produced, leaving 98.4 MMSTB of residual oil and more than 104 MMSTB of unrecovered mobile oil on University Lands. Bureau researchers have examined Queen sandstones in McFarland field and are now summarizing their results for a Bureau report.

Wolfcamp Carbonate Play

The Wolfcampian Series (Lower Permian) consists of a thick sequence of carbonates and siliciclastic rocks that constitute a relatively small but significant hydrocarbon play in West Texas. Total University Lands production from component reservoirs is more than 69 MMSTB, 5 percent of the total University Lands production. Wolfcamp reservoirs on University Lands are grouped into two subplays: (1) Central Basin Platform Shallow-Water Banks and Reefs, and (2) Delaware Basin Debris-Flow Carbonates.

Seven University Lands reservoirs are included in the Central Basin Platform Shallow-Water Banks and Reefs subplay, but most oil, more than 85 percent, occurs in the three largest reservoirs: Andrews South, Shafter Lake, and University Block 9. Cumulative production totals nearly 62 MMSTB, about 27 percent of the estimated original oil in place. The estimated remaining mobile oil totals 72 MMSTB. A single University Lands reservoir (War-Wink South Wolfcamp) is assigned to the Delaware Basin Debris-Flow Carbonates subplay. This deep-water carbonate reservoir consists of breccias, sandstones, and mudstones that were originally redeposited by debris flows, turbidity currents, and bottom currents on the lower slope and basin floor. Cumulative production at War-Wink South Wolfcamp totals more than 7 MMSTB, or 26 percent of the original oil in place. Remaining mobile oil is estimated at 5.4 MMSTB.

Pennsylvanian Platform Carbonate Play

A number of modest-sized oil fields located on the Central Basin Platform produce from Middle and Upper Pennsylvanian carbonates. Seven of the reservoirs included in this play have each produced more than 1 MMSTB of oil from University Lands. Reservoir facies of the northern five fields are phylloid-algal packstones and grainstones associated with carbonate mounds. Limited information from the southern two fields suggests that they produce from detrital limestones. Original oil in place on University Lands for the seven reservoirs is estimated to have been 200 MMSTB; cumulative production was 34 MMSTB as of 1988. Mobile oil that will remain on University Lands is estimated at 56 MMSTB.

Upper Guadalupian Platform Sandstone Play

Reservoirs in the Yates and Seven Rivers Formations along the western edge of the Central Basin Platform are included in this play. These reservoirs produce mainly from multiple sandstones associated with progradational tidal flat/lagoonal facies situated landward of shelf-margin reef deposits. Three University Lands reservoirs in this play contain an estimated 107 MMSTB original oil in place. Through 1987, 23 MMSTB have been produced from University Lands, leaving 61 MMSTB of residual oil and 23 MMSTB of unrecovered mobile oil. North Ward Estes is the largest of the three reservoirs, containing 16 MMSTB of target oil on University Lands.

Delaware Submarine-Fan Sandstone Play

The reservoirs of this play produce from well-sorted, very fine-grained sandstone interbedded with laminated and burrowed siltstone, organic-rich shale, and some limestone. The reservoir sandstone was deposited in broad channels along the lower slope and floor of the Delaware Basin. The three small reservoirs that occur on University Lands originally contained 40 MMSTB of oil in place; cumulative production to date is 5.8 MMSTB, Caprito reservoir accounting for more than half. Remaining mobile oil is calculated to be 9.2 MMSTB.

Simpson Group Marine Sandstone Play

Oil reservoirs of the Simpson Group Marine Sandstone play occur in the Connell, McKee, and Waddell sandstones of the Simpson Group along the Central Basin Platform. Only two reservoirs are included here in this play: Block 31 Connell and Martin McKee. Total cumulative production is 2.3 MMSTB of oil.

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

Charles Kerans, principal investigator;
F. Jerry Lucia, H. Seay Nance, Rainer K. Senger, Gary W. Vander Stoep, Mark H. Holtz, and Graham E. Fogg; assisted by Andrew P. Czebieniak, Malcolm A. Ferris, and Robert S. Single

The San Andres/Grayburg Reservoir Characterization Research Laboratory (RCRL) is an industry-sponsored project focused on developing methods to more efficiently recover remaining hydrocarbons in the prolific but highly heterogeneous San Andres and Grayburg reservoirs. The San Andres/Grayburg RCRL is currently supported by Agip, S. p. A., Amoco, ARCO, Chevron, Exxon, Marathon, Mobil, Shell, Texaco, and UNOCAL; Radian, Silicon Graphics and Stratamodel, Incorporated, are also supporting the RCRL through donation of in-kind software and hardware.

The San Andres/Grayburg RCRL is an integrated program applying geologic, petrophysical, engineering, geostatistical, and flow modeling studies in an effort to develop quantitative models of interwell heterogeneity for these complex reservoirs. Data are being collected from the outcrop, along the 17-mi-long Algerita Escarpment of the Guadalupe Mountains of New Mexico, and from the subsurface.

Model data are derived from outcrop geologic and permeability mapping as well as from three cored research wells taken immediately behind the mapped outcrop. Geologic studies during year one have focused on continuously exposed sections of stacked carbonate sand bodies that permit detailed assessment of sandbody geometry that is unavailable even in extensively cored reservoirs. Geologically guided permeability mapping has been carried out, thus documenting the heterogeneous nature of these reservoir-analog strata. This unique data set is currently being analyzed geostatistically and through iterative flow-modeling experiments to form a quantitative model for the selected facies tract.

Critical to the evaluation of the outcrop-based heterogeneity models is application and testing in the reservoir environment. To this end a parallel reservoir study is underway in the Seminole San Andres Unit, near the northern margin of the Central Basin Platform in the Permian Basin. Excellent core, log, and engineering data are available at Seminole, and these data have already shown many close parallels between the geologic structure in this reservoir and in the outcrop. Detailed petrophysical, engineering, and modeling studies planned for the 1989–90 project year will allow quantitative comparisons between outcrop and reservoir in terms of flow-unit structure and potential for unrecovered hydrocarbons.

Characterization of Facies and Permeability Patterns in Carbonate Reservoirs Based on Outcrop Analogs, Texas and New Mexico

Charles Kerans, F. Jerry Lucia, and Graham E. Fogg, principal investigators; H. Seay Nance, Gary W. Vander Stoep

This 2-year project is funded by the Department of Energy (DOE) and is an addition to the project "Characterization of San Andres and Grayburg Reservoirs" supported by the Bureau's Reservoir Characterization Research Laboratory (RCRL) Industrial Associates Program. In both projects the goal is to develop new methods of describing the three-dimensional distribution of remaining oil saturation and permeability in existing restricted platform reservoirs of the Permian Basin. The approach is to study the permeability and facies distribution in outcrops of the San Andres Formation and to test the resulting flow models in existing San Andres oil reservoirs. Funds provided by DOE are being used to extend the ongoing RCRL outcrop study to a different depositional facies tract.

Located in the southern Algerita Escarpment in the Guadalupe Mountains of Texas and New Mexico, this site is 9 mi south of the RCRL detailed study site. The regional geologic framework for the Algerita Escarpment shows that the RCRL study site is located in ramp-crest grainstone deposits of the upper San Andres and in inner-ramp fusulinid grainstones/packstones and mudstones of the middle San Andres. The new study area is located in a more basinward direction and will focus on outer-ramp clinoform deposits of the upper San Andres that are characterized by interbedded fusulinid grainstones and wackestones.

A flow model of the fusulinid-rich outer ramp deposits is a major objective of the study. Detailed three-dimensional facies maps will be prepared, and the outcrops will be sampled at various scales for porosity, permeability, capillary pressure, and rock-fabric studies. These data will be used in new geostatistical techniques for characterizing the permeability distribution. In turn, the flow model will be used to condition reservoir simulation studies designed to test various recovery methods. Comparable subtidal facies of the Dune (Grayburg) reservoir will serve as a subsurface data set for testing the applicability of the outcrop model.

Characterization of Carbonate Sandbar Facies in Grayburg Formation Reservoirs, West Texas

Charles Kerans, principal investigator; Don G. Bebout, F. Jerry Lucia, H. Seay Nance, Rainer K. Senger; assisted by Andrew P. Czebieniak, Malcolm A. Ferris, and Robert S. Single

Grayburg Formation reservoirs of the Permian Basin of West Texas contain a substantial resource base of unrecovered movable and residual hydrocarbons. These reservoirs exhibit highly stratified and heterogeneous pay intervals prone to low recovery efficiencies (10–30 percent). Because of their high hydrocarbon potential and geologic complexity, a program designed to develop improved methods of characterizing geologic heterogeneity and improving recovery efficiency of these reservoirs was developed. Funds for the research are provided in part by the U.S. Department of Energy through an interagency grant from the Texas Governor's Office.

The project will focus on characterizing the distribution, three-dimensional geometry, petrophysical/

engineering parameters, and flow-unit character of carbonate sand-body facies in the Grayburg Formation. Facies distribution will be defined through regional and more detailed subsurface studies along the eastern margin of the Central Basin Platform. The three-dimensional geometry of the carbonate sand bodies will be characterized using outcrops in the Guadalupe Mountains of New Mexico, where a variety of carbonate sands have accumulated in settings ranging from inner ramp to ramp crest.

Petrophysical and engineering studies, as well as geologic studies, will be undertaken during detailed characterization of portions of the Foster and Johnson Grayburg waterflood projects in Ector County, Texas. Flow-unit description and modeling will also be carried out in these reservoirs and compared with outcrop-based permeability patterns.

Activities for 1989 have involved reconnaissance mapping of Grayburg outcrops and data collection for the reservoir studies.

Vibracore drilling rig taking a shallow core of an ooid shoal at Joulters Cays, Bahamas. Such deposits represent a modern analog of major hydrocarbon reservoirs in the Permian Basin.

Heterogeneity in Modern Ooid Grainstones as Analogs for Ancient Hydrocarbon Reservoirs

Don G. Bebout, principal investigator; Paul M. Harris (Chevron), Mark H. Holtz, Charles Kerans, Richard P. Major, Allan R. Standen, Douglas C. Ratcliff, Noel Tyler, Gary W. Vander Stoep, Jim J. Kizer, and William H. Doneghy

Carbonate grainstones form major oil and gas reservoirs throughout the world. Reservoirs in the San Andres and Grayburg Formations of the Permian Basin provide excellent examples of this reservoir type. Subsurface and outcrop studies have documented extreme permeability variability within thin grainstone units of upward-shoaling cycles that occur within these formations.

The Bureau has initiated a study of a modern ooid grainstone bar at Joulters Cays, Bahamas. The goal of this research is to identify and map the distribution, extent, and geometries of internal heterogeneities within this active shoal. A coring program was designed to collect samples at spacing comparable to that of wells of a mature oil reservoir (between 20 and 40 acres per well). The study encompasses a 1- mi^2 area in which six cross-transects spaced 1,000 ft apart were laid out. Core stations were located every 1,000 ft along each transect. A core was taken at each of the 35 stations on 1,000-ft spacing.

Preliminary results suggest that internal fabric and stratal heterogeneity are controlled depositionally by subtle changes in grain size associated with various crossbedding and lamination types and diagenetically by laterally extensive early-cemented hardgrounds. These variations within the shoal result in significant permeability heterogeneity and are analogous to permeability variations encountered in ancient hydrocarbon reservoirs.

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

Noel Tyler and Robert J. Finley, principal investigators; R. Stephen Fisher, Mark H. Holtz, and Mark D. Barton

Co-funded by the Gas Research Institute and the Department of Energy, this research will address the poorly understood subject of composition, extent, geometry, pressure-dependent behavior, and geometric predictability of intrareservoir bounding surfaces in the context of a superbly exposed and cored outcrop belt, the Ferron Delta System in east-central Utah, and of an information-rich producing field, the Lake Creek (Wilcox) gas field immediately north of Houston. Mobil Exploration and Production, Inc., is supplying extensive data on the Lake Creek field; ARCO and UNOCAL have provided core and core data from stratigraphic test wells drilled basinward of the outcrop. This research is directed at examining the causes and predictability

of heterogeneity in fluvial-deltaic reservoirs, a reservoir class that has produced 64 percent of total production from Texas Gulf Coast fields. Predictability of reservoir and seal properties composes the crux of the project.

Planned research, which began in 1989, will (1) document and quantify the geometric and petrophysical attributes of flow units and their associated baffles, (2) quantify tensor attributes and properties of barriers to flow, and (3) determine the predictability of volumes and patterns of mass transport through the reservoir. The initial focus of the study is to map the distribution and geometries of Ferron sandstone facies and to integrate these data with an analysis of permeability distribution determined by using a portable minipermeameter. Analysis of the diagenetic overprint on the outcrop relative to the subsurface (determined from stratigraphic test wells on loan from industry) will form an integral element in the determination of flow units. Results of the Ferron study will be incorporated in ongoing analysis of Lake Creek reservoirs in the latter years of this 3-year project.

Maximization of Petroleum Recovery Efficiency in West Texas

Richard P. Major and Stephen C. Ruppel, principal investigators; Mark H. Holtz; assisted by Nestor D. Phillips and David A. Aliaga

The Permian Clear Fork Unit in Dollarhide field of West Texas is the focus of this project, which the State of Texas has funded through the Geoscience Institute as part of the Energy Research in Applications Program (ERAP). The aim of the Clear Fork study is to develop methods for improving productivity in major oil-bearing reservoirs in West Texas. Platform carbonate reservoirs, of which the Dollarhide Clear Fork Unit is an example, have accounted for almost half of the West Texas oil production and nearly as much of the remaining mobile oil resource (more than 17 Bbbl).

Clear Fork Group reservoirs are among the most heterogeneous of the platform carbonate class, as their typically low recovery efficiencies (average: about 20 percent) indicate. Clear Fork rocks comprise low-permeability, upward-shallowing cycles of low-energy, stable platform carbonates (principally dolostone) that exhibit marked lateral and vertical variations in mineralogy, lithology, and porosity caused by original depositional conditions as well as by subsequent diagenetic alteration.

The Bureau, working with a consortium of geoscientists and engineers from The University of Texas, Texas A&M University, the University of Houston, and Texas Tech University, in cooperation with UNOCAL, the field operator, is conducting a detailed characterization of the Dollarhide reservoir. The goal of the project is to develop an integrated geological model to define flow unit geometries and facilitate more efficient recovery of the remaining oil. Exploitation models developed in the course of the Dollarhide study should be applicable both to other Clear Fork reservoirs and to other restricted platform reservoirs in West Texas.

State Lands Energy Resource Optimization (SLERO) Project

Noel Tyler, director; Richard P. Major, principal investigator; Mark H. Holtz, J. Ulises Ricoy, Douglas S. Hamilton, Fred P. Wang, Chester M. Garrett, Jr.

The Office of the Governor has awarded research funds to a consortium of State universities to establish a State Lands Energy Resource Optimization (SLERO) Center to be housed at the Bureau of Economic Geology. Members of the consortium are the University of Houston, Texas A&M University, Texas Tech University, and The University of Texas at Austin. The Bureau has been assigned overall management and coordination of the project. Work will also be performed by other University of Texas at Austin departments such as the Center for Petroleum and Geosystems Engineering, the Department of Chemistry, and the Department of Geological Sciences. The Houston Area Research Center and the General Land Office of Texas will also be involved.

This research and development program involves the use of advanced geologic, engineering, and geophysical approaches to reservoir development for the implementation of improved recovery strategies on candidate State Lands reservoirs. Initial studies will be concentrated on State Submerged Lands reservoirs and will be expanded during later years to address onshore State Lands reservoirs. Projects will emphasize the near-term potential of these producing reservoirs to benefit Public School Funds.

Project SLERO is divided into three major research activities. The first is play analysis and resource assessment. A comprehensive inventory of all data from State Lands, principally available from the General Land Office, the Railroad Commission, and the Bureau's oil and gas reservoir data base, will be made to provide a framework within which these reservoirs may be divided into plays. Play analysis will guide strategic focusing of further research eflorts on those State Lands plays that have the highest potential for increased production as the result of advanced geoscientific understanding and production technology. A quantitative assessment of remaining resources (mobile oil,

residual oil, and gas) will be made for each play. Results of this assessment will be used to define producing plays most amenable to improved recovery through near-term implementation of research results. This procedure will ensure that the study of reservoirs selected within these trends will apply directly to a large class of reservoirs that make up a substantial target of unrecovered hydrocarbons.

The second research activity, the primary Bureau focus, is reservoir characterization of selected State Lands reservoirs. Initial results of the resource assessment activity will be used to identify five specific reservoirs for detailed, multidisciplinary investigation. Each of these reservoir studies will begin with construction of a geological framework within which combined geologic, engineering, and geophysical investigations will be conducted to delineate reservoir architecture and flow unit geometries. This will provide the basis for identifying the quantity and location of remaining hydrocarbons and determining appropriate advanced strategies for hydrocarbon recovery.

The third research activity is development of advanced extraction technology designed especially for maximum impact on State Lands reservoirs. This activity will address the effects of advanced well stimulation and enhanced oil recovery technologies.

Estimation of Economically Recoverable Unswept Mobile Oil

Noel Tyler and Robert J. Finley, principal investigators; Mark H. Holtz, William A. Ambrose

This project, conducted jointly by the Bureau and ICF Resources, Incorporated, is funded by the Bartlesville Project Office of the U.S. Department of Energy. The aim of the study is to determine what volume of the large unrecovered mobile oil resource base remaining in Texas reservoirs is economically recoverable. This project has expanded the Bureau's oil reservoir data base to include reservoirs that have produced more than 5 MMbbl 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.

The primary objective of the study was to compare the economic benefit of targeted infill drilling with that obtained by uniform reductions in well spacing. The comparison was undertaken only in reservoirs in which uniform infill drilling was found to be economic. At prices of $20 per barrel, targeted infill drilling potentially may recover 350 percent more oil than is recovered in a single reduction in well spacing in the analyzed reservoirs. If uniform drilling is continued to economic limits, geologically targeted infill drilling can still produce a 10 percent greater volume of recovery and at a cost 17 percent less than that incurred by uniform infill drilling. Our analysis suggests that primary recovery by targeted infill drilling alone will account for an incremented recovery of 18 percent of the remaining mobile oil resource base. Potential for additional recovery through advanced secondary techniques (largely waterflood redesign to access unswept reservoir compartments) will be addressed in future studies.

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

Larry W. Lake, Department of Petroleum Engineering, The University of Texas at Austin, principal investigator; Graham E. Fogg

This project is aimed at developing procedures for more realistic modeling of heterogeneous reservoirs. Specifically, this involves devising and testing methods for translating local-scale data on absolute permeability and relative permeability of reservoirs into "effective" rock properties that are representative of fluid flow and mass transport at the scale of a reservoir simulator block. This problem has historically hindered efforts to accurately model heterogeneous reservoirs.

Through the use of numerical modeling experiments, both empirical and theoretical relationships between effective permeability and certain properties of a fluvial sand and mud sediment package are being established. These properties include sand percent and the ratio between average horizontal and vertical facies dimensions relative to dimensions of the simulator block. With minor modification the derived relationships can be extended to other rock types. Results will include guidelines for assigning effective permeability values to simulator blocks based on measurable geologic properties of the porous medium.

Relative permeability occupies the same role in mutiphase flow as does absolute permeability in single-phase flow. Previous approaches for scaling rock-relative permeability curves to larger reservoir volumes have neglected important viscous effects and the presence of discontinuous absolute permeability. Therefore, a principal aim of the study is to develop a relative permeability averaging procedure based on a modified vertical equilibrium concept for which both viscous effects and discontinuities are accounted. Accuracy of this method will be tested via numerical modeling experiments concerning oil and water movement in realistically heterogeneous media.

Gas

Geological Investigations of Low-Permeability Gas Sandstone Reservoirs

Shirley P. Dutton, principal investigator; H. Scott Hamlin, Tucker F. Hentz, Stephen E. Laubach, and Robert S. Tye; assisted by Sabine C. Boardman, Robert L. Buehring, Timothy N. Diggs, Karen L. Herrington, and Andrew R. Scott; in cooperation with the Wyoming Geological Survey

Since 1982 the Gas Research Institute (GRI) has supported geological investigations designed to develop knowledge necessary to efficiently produce natural gas from low-permeability sandstone reservoirs. As part of this program, the Bureau has been conducting research on low-permeability sandstones in the Lower Cretaceous Travis Peak (Hosston) Formation and the Jurassic Cotton Valley Group in East Texas. 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.

In 1989, research was extended to include the Frontier Formation in the Green River Basin, Wyoming, and the Cleveland Formation in the Anadarko Basin, Texas Panhandle. This new phase of research on low-permeability sandstones will lead to the drilling of a Staged Field Experiment (SFE) well in 1990 in a new basin to test the extent to which technology and methodology developed for the Travis Peak and Cotton Valley Formations in East Texas can be transferred to other low-permeability sandstones. The Frontier and Cleveland were chosen following systematic evaluation of low-permeability, gas-bearing formations throughout the U.S.; these two formations were judged as having the best opportunities for meeting the project's research objectives and for drilling an SFE well. Other research in 1989 included (1) continued evaluation of data from a GRI-operated test well in East Texas that was drilled in the Cotton Valley in 1988 (the SFE No. 3 well) and (2) synthesis of structural, stratigraphic, and diagenetic controls on gas production from low-permeability Travis Peak reservoirs.

Geological research objectives for the study of the Frontier Formation along the Moxa Arch in the Green River Basin are divided into three major areas: (1) depositional systems and distribution of reservoir sandstones; (2) diagenetic history of the formation and modifications of original reservoir quality; and (3) structural geologic history and current structural setting of the tight gas basin and its contained reservoirs. Results from both regional and local investigations in these three areas will provide a basis for locating a site for SFE No. 4. Integration of abundant well log, core, and outcrop data has provided an excellent opportunity for stratigraphic analysis of the Frontier Formation. The regional stratigraphic framework was outlined during 1989, including lithologic mapping and depositional systems interpretations. Cores were available for calibrating well logs and interpreting depositional processes and facies. Outcrops located around the basin margin added an important lateral dimension to facies analysis.

Detailed stratigraphic and petrographic studies have been conducted in several areas along the Moxa Arch, including Fontenelle, Church Buttes, and Bruff fields. These studies have included mapping structure and sandstone geometry and construction of detailed stratigraphic cross sections. Microscopic-scale characteristics of Frontier reservoirs in these fields were studied by standard thin-section petrography, scanning electron microscopy, and X-ray analysis. In addition to determining the diagenetic history of the Frontier reservoir sandstones, goals of the petrographic work are to determine variability in detrital and authigenic mineral content of the Frontier along the Moxa Arch and to evaluate potential fluid sensitivity of the reservoir facies.

Structural geologic studies of the Frontier are being conducted to assess the distribution of natural fractures and the controls on hydraulic fracture orientation and propagation in the reservoir. Subsurface structural geologic mapping, investigation of macro- and microfractures, and delineation of stress states, including vertical stress variations, are methods being used to characterize the structural state of the reservoir. This type of information will be combined with published and acquired stress-direction data from hydraulic fracture treatment and borehole breakouts to provide the context for interpreting stress-direction indicators such as acoustic anisotropy of core collected during evaluation of potential sites for SFE No. 4. Such information is useful for predicting propagation direction of hydraulic fractures.

Study of low-permeability sandstone in the Pennsylvanian (lower Missourian) Cleveland Formation of the western Anadarko Basin also began in 1989. Work has concentrated on the detailed stratigraphic correlation of the unit within the 5,270-mi^2, seven-county study area (Hansford, Ochiltree, Lipscomb, Hutchinson, Roberts, Hemphill, and Wheeler Counties) of the northern Texas Panhandle. Upon completion of regional correlations, the study will focus on a depositional-systems and diagenetic analysis of the formation. Core from the Cleveland will allow direct inspection of sedimentary features and reservoir properties.

Atlas of Major Texas Gas Reservoirs

Robert J. Finley, principal investigator; 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

The Gas Research Institute and Bureau of Economic Geology funded this research project to collect, assimilate, and publish data on the geological and engineering characteristics of major gas reservoirs of onshore Texas. Almost 2,000 reservoirs, those with cumulative production of greater than 10 Bcf, are included in this compilation. This project has been completed, and the publication *Atlas of Major Texas Gas Reservoirs* is now available.

All of these Texas reservoirs have been organized into 73 geologically based groups (plays) to permit ready comparison of reservoir characteristics and to delineate producing trends. Age, formation, lithology, reservoir genesis, and geographic location were used to define the plays. Thirty of these plays are from the Gulf Coast, the largest gas-producing region in Texas. Following the Gulf Coast in numbers of plays are West Texas (19 plays), East Texas (11 plays), Texas Panhandle (8 plays), and North-Central Texas (5 plays).

Both nonassociated and associated gas are considered for calculating the volumetrics presented in this atlas. Nonassociated gas is that produced from reservoirs in which gas is the primary resource with little, if any, liquid hydrocarbon. Associated gas is produced from oil reservoirs as gas-cap gas (associated gas-well gas) or as gas in solution in the oil (associated casing-head gas). Gas Atlas data are now being actively used in formulating strategies for increased natural gas recovery under the secondary gas recovery project.

National Gas Atlas

Don G. Bebout, principal investigator; Chester M. Garrett, Jr., and William A. White; assisted by Matt L. McCullough. With subcontracts for the first phase to Arkansas Geological Commission, Louisiana Geological Survey, Mississippi Department of Natural Resources, and Geological Survey of Alabama for the Central and Eastern Gulf Coast portion; and subcontracts for the second phase to Arkansas Geological Commission, Kansas Geological Survey, and Oklahoma Geological Survey for the Midcontinent portion

The Gas Research Institute has provided funding to the Bureau to collect and organize data on major gas reservoirs of the Central and Eastern Gulf Coast and Midcontinent regions and to publish the results in the same format as that of the Bureau's *Atlas of Major Texas Gas Reservoirs*. Subcontracts have been awarded to the geological surveys from the major gas-producing states in these two regions (listed above) for collection and compilation of data from reservoirs located in their respective states. The first phase of the project includes the collection of data from the Central and Eastern Gulf Coast for the first year of the project. The second phase (year two) includes collection of data from the Midcontinent region while the data from the Gulf Coast are being incorporated into an atlas format. The Midcontinent data will be assimilated and organized for an atlas during the third phase (year three).

The major reservoirs (cumulative production greater than 10 Bcf) will be assembled geologically into plays using age, formation, lithology, reservoir genesis, and geographic location as organizational criteria. Reservoirs grouped in this manner generally have similar production characteristics that can be extrapolated to lesser-known reservoirs within the same play.

The two atlases resulting from this project will be available from the Bureau and from each of the participating geological surveys.

Assessment of Gas Resources for Secondary Gas Recovery Technology

Robert J. Finley, principal investigator; Mary L. W. Jackson and William A. Ambrose

The purpose of this project, which was completed for the Gas Research Institute, was to provide an initial evaluation of geologically based infill drilling and recompletion of bypassed gas zones as sources of increased gas reserves that can be produced at competitive prices. Recognizing that these practices are not yet widespread but are expected to increase, historical approaches to field development were evaluated as an indication of incremental recovery potential.

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 leads to the occurrence of bypassed reservoirs that have not been fully drained and to the partial isolation of reservoir compartments that remain to be tapped.

Assessment of incremental gas resources available from specific reservoirs was found to be highly sensitive to timing of new wells and their placement areally within

the boundaries of existing development. Fewer wells in deltaic systems contact greater volumes of natural gas, as might be expected based on a lesser degree of heterogeneity compared to fluvial-deltaic reservoirs. In fluvial-deltaic reservoirs, rapid changes from sand-rich to sand-poor channel to floodplain facies compartmentalize productive reservoir facies. In the Jim Wells reservoir in La Gloria field, an isolated, dip-oriented channel belt in the southeastern part of the field was found to contain no perforations, forming a potential target for strategic infill drilling. A geologically based infill-drilling strategy for a heterogeneous reservoir such as the Jim Wells involves integration of four critical factors: (1) lateral reservoir heterogeneity, illustrated on facies maps, (2) vertical reservoir heterogeneity, displayed on maps showing net-shale vertically isolating individual reservoir stringers, (3) distribution of older perforated wells, and (4) field structure and elevation of the gas-water contact. Success in gas infill drilling was noted in the report on Stratton field, also containing fluvial-deltaic Frio reservoirs, and located along depositional strike to the northeast of La Gloria field. Coordinated engineering and economic analyses were conducted by ICF Resources, Incorporated.

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

Robert J. Finley, project director; Edgar H. Guevara, Shirley P. Dutton, and L. F. Brown, Jr., coprincipal investigators; Jeffry D. Grigsby, Lee A. Jirik, Dennis R. Kerr, Richard P. Langford, Chris Mijnssen, E. G. Wermund, and Sally G. Zinke; assisted by Mark D. Barton, James G. Brewton, Becky J. Cole, Karen L. Herrington, Jairo M. Lugo, F. Leo Lynch, Jesus A. Maguregui, and Thomas A. Williams

This three-year-long multidisciplinary research program was initiated in the last quarter of 1988 and is cooperatively funded by the Gas Research Institute, the U. S. Department of Energy, and the State of Texas. Objectives of the project are (1) to develop and field test methods for determining the distribution of unrecovered, conventional natural gas resources by depositional system and (2) to maximize ultimate recovery of these resources. Research targets are gas accumulations that occur in known fields in stratigraphically controlled, untapped, and partly drained reservoir compartments and closely related deeper pools. Research results will better enable natural gas producers to economically define and develop natural gas within known conventional fields. Project management is by the Gas Research Institute; the Bureau of Economic Geology functions as Lead Technical Contractor and coordinates research carried out by four task groups. Geological studies are by the Bureau of Economic Geology. ResTech, Inc., of Houston, conducts well-log analysis and formation evaluation studies. Research and Engineering Consultants of Englewood, Colorado, conducts engineering and reservoir modeling investigations. Envirocorp Services and Technology of Houston monitors drilling and completion activities in gas fields, particularly in the South Texas coastal plain, and coordinates data acquisition operations in cooperative wells.

Studies in 1989 focused on heterogeneous Tertiary, fluvial and deltaic sandstone reservoirs in the South Texas portion of the Gulf Coast Basin. A comprehensive workplan of integrated geological, petrophysical, geophysical, and engineering studies was developed, and a computerized data base system was acquired to manage the extensive and diverse information used in the interdisciplinary studies. Geological and engineering screening of fields that lately have had relatively high levels of drilling and completion activities resulted in the selection of four multipay fields (Lake Creek, Seeligson, Stratton-Agua Dulce, and McAllen Ranch) for studies of reservoir heterogeneity and data acquisition in cooperative wells. These fields have good potential for the occurrence of uncontacted and partly drained reservoir compartments and represent the spectrum of Tertiary fluvial-deltaic reservoirs in Texas. Producing intervals are fluvial and deltaic sandstones in the Oligocene Frio Formation (in Seeligson and Stratton-Agua Dulce) and deltaic sandstones in the Eocene Wilcox Group (in Lake Creek) and Oligocene Vicksburg Formation (in McAllen Ranch).

New data were acquired in two deeper pool tests drilled by Mobil Exploration and Producing U.S., Inc., in Seeligson field and in two development wells drilled by Shell Western E&P Inc. in McAllen Ranch field. The data consist of cores, open-hole and cased-hole well log suites, offset vertical seismic profiles (VSP's), and sequential reservoir pressure measurements. In addition, a zero-offset VSP survey was recorded in a well deepened by Mobil in Lake Creek field during the last quarter of the year. Data acquisition was in progress at the end of the year in Seeligson field in unitized Frio reservoirs operated by Oryx Energy Company (formerly, Sun Exploration and Production Company). Cased-hole logs, offset VSP's, cross-borehole seismic tomography, and pressure interference data will be obtained in producing and temporarily abandoned wells owned by Oryx. A key objective of this effort is the integration of multiple approaches to defining reservoir heterogeneity and the use of one approach to help confirm and complement another. Pressure interference testing will, for example, help define actual flow capability between wells for validation of the physical framework defined by geophysical methods.

Project results confirm the occurrence of heterogeneous reservoirs in the fields studied and indicate that stratigraphic heterogeneity in the interwell areas can be defined using integrated geological, engineering, and borehole geophysical techniques that target bypassed reservoirs and untapped compartments. Reflection terminations in VSP data permitted further delineation of lateral reservoir discontinuities previously interpreted using well logs and slabbed cores. Moreover, several Frio reservoirs in the cooperative wells in Seeligson field have pressures that are significantly higher than those last measured in nearby producing wells, suggesting that the newly drilled wells tapped partly drained reservoir compartments. Similarly, pressure variations of up to 600 psi were found in parts of the target reservoir in McAllen Ranch field's cooperative wells, indicating that individual deltaic depositional lobes may not be uniformly depleted by existing wells. Diagenetic heterogeneity was indicated within delta-front sandstones that may impart a directional permeability anisotropy to these reservoirs.

Project work for next year will include the drilling and completion of a research well designed to test in detail concepts of fluvial-deltaic sandstone reservoir compartmentalization. Also in 1990, screening of carbonate reservoirs suitable for project studies will begin.

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

Regina M. Capuano

This study is part of a two-year 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 CO_2 and CH_4 saturation and to assess how saturation may affect the composition of diagenetic alteration. Funds for this study are provided through the Texas Higher Education Coordinating Boards' Texas Advanced Research Program.

Previous research has shown that CO_2 and CH_4 are released as products of kerogen decomposition during sediment diagenesis and that the hydrologic conditions present in geopressured sediments favor enrichment of pore fluids in these gases. There is a common association of CH_4-dominated gas fields with petroleum occurrences in the upper portions of the geopressured section; this could permit the inference that the associated brines are saturated with CH_4. The enrichment of CO_2 is not as readily apparent. Analysis of gas samples collected from gas fields is not representative of the amounts of CO_2 present in the associated brines.

Two hydrologically distinct geopressured areas along the Texas Gulf Coast are to be studied. The first study area includes Chocolate Bayou and Pleasant Bayou fields in Brazoria County, Texas. Wells from these fields derive their fluid from the Oligocene Frio Formation, which is composed of sandstone-shale units. This site was selected because the stratigraphy and the diagenesis of the Frio Formation from the area have been well described and because numerous wells intersect the geopressured section over the temperature range of interest. Preliminary results from this field indicate that the brines present in the upper portions of the geopressured section are higher in CO_2 than previously reported. Potential sites for the second study area are currently being evaluated.

Geologic Evaluation of Critical Production Parameters for Coalbed Methane Resources

Walter B. Ayers, Jr., principal investigator; William R. Kaiser, William A. Ambrose, and Stephen E. Laubach; assisted by Joseph S. Yeh, Thomas E. Swartz, Jeffery D. Beckman, Patrick S. Reiss, Gregory A. Warren, David R. Grote, Wahiduzzaman Mirza, Wendy J. Garey, and Jermillah N. Ashton; in cooperation with the Geological Survey of Alabama, Colorado Geological Survey, and New Mexico Bureau of Mines and Mineral Resources

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 (New Mexico and Colorado) and Black Warrior (Alabama) Basins, the major coalbed-methane-producing basins in the United States. The Bureau is leading research on the Upper Cretaceous Fruitland Formation of the San Juan Basin; the Colorado Geological Survey and the New Mexico Bureau of Mines and Mineral Resources are subcontracted for parts of the study. The Geological Survey of Alabama is subcontracted to study coalbed methane in the Lower Pennsylvanian Pottsville Formation of the Black Warrior Basin.

In the second year of this study, research in the San Juan Basin was divided into sedimentologic, fracture, hydrologic, and production studies. The sedimentologic study showed that the occurrences and trends of Fruitland coal seams are controlled by depositional setting. The thickest coal seams (individual seams thicker than 20 ft and net-coal thickness more than 50 ft) formed landward (southwestward) of the northwest-trending Pictured Cliffs barrier-strandplain; other coal seams trend northeastward and formed in a floodplain setting between Fruitland fluvial systems. Coalbed-methane resources in coal seams thicker than 2 ft in the Fruitland Formation were calculated to be 49 Tcf between the depths of 400 and 4,200 ft.

Permeability, the most critical parameter for the production of coalbed methane, is controlled primarily by natural fractures. Preliminary studies of outcrops and cores show that cleats (fractures in coal seams) in Fruitland coal seams and joints in the Upper Cretaceous and Tertiary rocks in the San Juan Basin are extensional fractures. Face (dominant) and butt (subordinate) cleats in Fruitland coal seams are well developed, orthogonal, and nearly perpendicular to bedding. Folds may be sites of fracture-enhanced coalbed permeability, and they may form conventional traps. Fractures are inferred to occur in major folds such as the Hogback Monocline, which rims the northern half of the basin and the Ignacio and Bondad Anticlines, and in several minor tectonic folds, which have less than 100 ft of structural relief, at the periphery of the basin floor. Additional targets for fracture-enhanced permeability are compaction-induced folds and fractures that are inferred to exist where coal seams override or underride Pictured Cliffs and Fruitland sandstones.

In the north-central part of the San Juan Basin, Fruitland coal seams are aquifers and are overpressured due to artesian conditions or aquifer confinement, and they pinch out basinward. Potentiometric-surface and chlorinity maps show that recharge occurs primarily at the elevated north and northwest margins of the basin; flow is southeastward into the basin. Although the Fruitland Formation behaves regionally like a hydrologic unit, some wells have large pressure gradients and produce anomalously large or small volumes of water, indicating reservoir compartmentalization. Coalbed-methane production in the San Juan Basin is primarily from the overpressured, north-central part of the basin, but production is substantial from the southern part of the basin, either directly or indirectly from underpressured coal seams. Coalbed-methane production in the San Juan Basin is log-normally distributed. Initial potential from coalbed-methane wells is bimodal; the primary modal class is 100 to 178 Mcf/d. The second mode is 592 to 1,000 Mcf/d, and it coincides with the modal class for Fruitland sandstone wells, indicating that some coal seams have free gas and significant fracture permeability.

The Black Warrior Basin contains an estimated 20 Tcf of methane in coal seams of the Upper Pottsville Formation. Researchers at the Geological Survey of Alabama studied sedimentology, hydrology, fractures, and production to identify geologic and hydrologic controls on the occurrence and producibility of coalbed methane. They concluded that geologic factors, including the depositional setting, rank, and quality of coal, determine the distribution of coalbed-methane resources. Coal seams are most abundant (locally more than 30 seams) and highest in rank (low-volatile bituminous) in the southeastern part of the basin, where they are associated with thick packages of lithic sandstone that were deposited in a rapidly subsiding part of the basin.

To further evaluate coalbed-methane producibility, hydrologic and structural studies were used to identify areas with high permeability. Highly productive coalbed-methane wells are localized and appear to coincide with northeast-trending lineaments, which are thought to be surface expressions of fracture zones. East-northeast-oriented maximum horizontal compressive stress may contribute to permeability anisotropy, causing northeast-trending fractures to be open, whereas northwest-trending fractures are closed.

Coal

Computerized Calculation of Lignite Resources in Texas

William R. Kaiser, principal investigator; Mary L. W. Jackson; assisted by Najib F. Ghandour and Laura L. Moffett

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 (Coal Resource Classification System of the U.S. Geological Survey). Seam thickness (nearest half-foot) and depth are coded from geophysical logs and entered into the data base using the USGS stratigraphic data form. Plotted point-source data are digitized for entry. Resources are calculated for five seam-thickness categories and three certainty categories using PACER (establishes thickness categories), VLATLONG (prepares PACER files for use in GARNET), and GARNET (grids, contours, and calculates resources). Resources are aggregated by stratigraphic unit, mapped, and reported by region.

Resources were calculated for the Jackson/Yegua trend in East Texas, the outcrop area extending from Fayette County at the south, northeastward to San Augustine County. Data entry for the Jackson and Wilcox trends of South Texas has begun and resource calculation should be completed early in 1990. Resources in the Wilcox trend of East Texas were calculated earlier, and a Bureau report on Wilcox lignite is being edited for publication.

Jackson/Yegua resources in seams 2 ft thick or more total 6,300 million short tons with demonstrated resources (measured and indicated) of 2,200 million tons, or those known with highest certainty, accounting for 35 percent of the total. In contrast, total resources of 7,500 million tons with demonstrated resources of

4,800 million tons (64 percent of the total) are reported in Report of Investigations (RI) No. 104. In RI 104, resources were calculated using geologic models and reported lignite occurrences to estimate resources in Lee, Burleson, Trinity, Angelina, and San Augustine Counties for which there are no point-source data. The NCRDS method is highly data dependent and in the absence of point-source data can make no allowance for resources that can be estimated with moderate certainty using geologic models. In contrast, the methodology of RI 104 does that, and therefore the demonstrated resources documented in it are larger than those calculated by NCRDS. The size of NCRDS certainty categories, defined by increasing radii about control points, will always cause the majority of its coal resources to be inferred, because the inferred radius is four times that for demonstrated resources. In the methodology of RI 104, the size of the inferred category, or that known with the least certainty, was constrained by the geologic models.

Experimental and Applied Tectonics Investigations

Applied Geodynamics Laboratory

Martin P. A. Jackson, laboratory director; Bruno C. Vendeville, Daniel D. Schultz-Ela, and John G. Sclater; assisted by Shing-Tzong Lin and Ridha C. Gharbi

The Applied Geodynamics Laboratory (AGL) is designed for physical and mathematical scale-modeling of the mechanics of tectonic and structural geologic processes. Research at AGL is funded by an industrial associates consortium comprising the following oil companies: Agip, S.P.A., Amoco Production Company, ARCO Oil and Gas Company, BP Exploration Inc., Chevron O.F.R. Company and Chevron U.S.A. Inc., Conoco Inc., Elf-Aquitaine Petroleum, Exxon Production and Research Company, Marathon Oil Company, Mobil Research and Development Corporation, Petroleo Brasileiro S.A., Phillips Petroleum Company, Texaco Inc., and Total Minatome Corporation.

Since AGL was established in September 1988, much of the first year's activities have been associated with technical development. This included the design, fabrication, purchase, and testing of equipment and pilot experiments on the rheologic behavior of different materials in various combinations. For modeling in an accelerated gravity field, a high-speed, high-capacity centrifuge, which includes a rotor designed specifically for tectonic modeling, was manufactured, customized, and installed. The machine is equipped with a viewing port, stroboscopic lighting, slip rings, digital speed control, and temperature control. For modeling in a normal gravity field, a deformation rig was designed and fabricated. Its flexible design allows simulation of almost any structural style, including extension, shortening, wrenching, doming, and drape folding, or any combination of these styles. The rig comprises (a) a modular framework (6 × 4 × 3 ft) that can be assembled in many configurations, (b) four 2-ton screw jacks, (c) flexible drive shafts, (d) a stepper motor, (e) an electronic indexer, and (f) a personal computer for control. Other equipment includes modeling boxes and photographic equipment. Modeling materials include silicone polymer, silicone putties, Plasticine, pure quartz sands, glass sand, glass bubbles 25–60 μm in diameter, clays, paraffin waxes, dyes, and computer-generated, printable grids of strain markers.

Vertical section through a physical model of diapirs (dark, at bottom) developing during thin-skinned extensional faulting. The shape and location of the modeled diapirs were strongly controlled by faulting in the overburden of stratified sand.

Experimental research during the year focused on a wide range of gravity-driven tectonics involving extension, salt tectonics, and combinations of these structural styles. The research aims to elucidate the location, origin, mechanics, and evolution of structural hydrocarbon traps. The dynamically scaled models are designed to test hypotheses or duplicate specific geologic structures. Experiments covered the following

topics: (a) growth of salt tongues in extensional and contractional regimes; (b) origin of discordant lower contacts of salt tongues; (c) interaction of brittle overburden and ductile substrate and influence of sediment-deposition rate on structural style during gravity tectonics; (d) piercement of brittle overburden by postdepositional diapirs; (e) control of overburden thickness and diapir width on initial piercement of diapirs; (f) emplacement of diapirs concurrently with sedimentation; (g) influence of overburden faults on diapirism; and (h) diapiric extrusion.

Two Macintosh-based computer programs were written to quantify the deformations in the models and in their natural equivalents. They enable geologic structures and hydrocarbon traps to be correlated with the scaled models. The first program structurally restores cross sections. It geometrically reverses the effects of faulting, diapirism, and sedimentation by sequentially removing layers and fault slip while correcting for compaction, rotation, and folding. The second program calculates local strains from the deformed traces of an originally vertical or horizontal undeformed grid imprinted on or in a physical model.

Salt Tectonics on the Continental Slope, Northern Gulf of Mexico

Martin P. A. Jackson, principal investigator; Steven J. Seni; assisted by Jeffrey W. Black

The Texas Higher Education Coordinating Board, under the Advanced Technology Program, funded this 2-year research project in September 1988 to investigate salt tectonics on the continental slope of the northern Gulf of Mexico. The deep Gulf is a prominent area for research in salt tectonics because the structures are shallow and thus readily imaged on high-quality seismic records and because structural evolution is ongoing. Furthermore, the recent history of salt tectonics on the slope may help us understand the evolution of older structures onshore whose evolution is obscured by deep burial. Understanding the history of salt migration is also important for the petroleum exploration industry because salt flow creates a wide range of subtle traps for migrating petroleum.

Halliburton Geophysical Services (formerly Geophysical Services Inc.) donated a three-dimensional seismic exploration data grid, 2000 km^2 in extent, from the Green Canyon Area. These data were the primary source of information used to study salt tectonics. Additional data include regional two-dimensional seismic lines and information from more than 30 wells and paleontologic reports.

A wide range of salt structures and depositional basins is present on the slope. Allochthonous salt sheets, irregular salt massifs, cylindrical salt stocks, and salt-confined depotroughs all occur on the continental slope in the Green Canyon Area. Large counter-regional growth faults typically form the updip margin of many allochthonous salt sheets and massifs. These faults form ramps connecting sheets of allochthonous salt at different levels. Other enigmatic features include remnant salt structures and turtle-structure anticlines in areas from which most salt has already been evacuated. The key to understanding and predicting the synergistic relationship between salt and sediment lies in deciphering the sedimentary record of deposition and deformation around salt structures. Palinspastic reconstructions based on sequential backstripping decompacted sediment layers have proved useful for analyzing the history of salt movement.

Mechanics of Segmentation along Normal Faults

Jay A. Raney, principal investigator; Stephen E. Laubach

This project, funded by the Texas Higher Education Coordinating Board, investigates how segments of normal faults grow and 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. Normal fault systems provide economic opportunities and pose environmental hazards in different parts of Texas. This study is intended to provide a better understanding of the mechanics of normal faulting that will lead to better prediction of economic deposits localized along faults and mitigation of environmental hazards associated with normal faults.

Laboratory scale-modeling experiments were undertaken on two automated deformation tables donated by Exxon Production Research Company. These instruments can deform rock-analog materials at low strain rates to simulate formation of faults in nature. Dynamic scaling and appropriate deformation modes must be achieved in model materials to ensure appropriate modeling of natural large-scale deformation. During 1989, model materials and experimental procedures for simulating the mechanical interaction of faults were designed and tested, and the deformation modes of various model materials were characterized under a range of conditions. Products of several experiments have striking geometric similarity to faults in naturally deformed rocks. Fault segments, fault branches, grabens, antithetic and synthetic faults, rollover structures, and accommodation zones were created under controlled conditions. These experiments permitted the

growth of fault patterns that closely resemble fault patterns in nature to be monitored. Continuation of laboratory studies in 1990 with the recently completed automated deformation rig in the Applied Geodynamics Laboratory will allow new materials to be used that have closer mechanical similarity to rocks and that are more readily sectioned for three-dimensional views of fault interactions.

The objective of field studies of normal faults in this project is to test and refine hypotheses derived from modeling experiments. An area in the Basin and Range province of Arizona containing numerous small segmented and intersecting normal faults was selected for detailed study. Maps, detailed cross sections, and block diagrams were made to document fault configurations, cross sections were sequentially restored, and fault interactions in three-dimensions were documented by outcrop mapping and with serial sections through hand samples. Petrographic characteristics of the faults and adjacent rocks were also examined. This aspect of the study is also providing new insight into the details of fault-block shape in extended terrains. These results have implications for the internal structural complexity and physical heterogeneity of large fault blocks and compartmentalization in faulted petroleum reservoirs. Several invited presentations to representatives of the oil and gas industry on the results of the field studies were made during 1989.

Land, Water, and Environmental Resources Investigations

Waste Isolation Studies

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

Jay A. Raney, program coordinator; Alan R. Dutton, principal investigator for hydrologic studies; M. Saleem Akhter, Robert W. Baumgardner, Jr., Edward W. Collins, Carolyn E. Condon, R. Stephen Fisher, Thomas C. Gustavson, Rodney I. Heathcott, William F. Mullican III, Bernd C. Richter, Jeffrey N. Rubin, Bridget R. Scanlon, Rainer K. Senger, G. Stephen Stubbs, and Fred P. Wang; assisted by Arten J. Avakian, Lehar M. Brion, George T. Bush, Min-Yuan Cheng, James A. Doss, Sung-Chi Hsu, Joong H. Kim, Juinnren Lai, Daniel H. Ortuño, Richard H. Raymond, and Heng Tsai

Evaluation of the geology and hydrology of a potential site for a repository of low-level radioactive wastes continued during 1989. This work, funded by the Texas Low-Level Radioactive Waste Disposal Authority, focuses on an area designated by the Authority north of Fort Hancock, Hudspeth County, Texas. The Bureau also coordinated geotechnical investigations conducted by faculty and students from the Civil Engineering Departments at The University of Texas at Austin and The University of Texas at El Paso, and geophysical studies by staff of the Department of Geological Sciences at The University of Texas at El Paso. Draft reports on the initial results of these investigations were submitted to the Authority in August. Most of the remaining data collection and analysis was accomplished during the fall of 1989.

The geologic studies include investigations of the stratigraphy, structural geology, and geomorphology of the study area. Both site-specific and regional investigations of the host stratigraphy have been accomplished. Interpretations of depositional environment, historical development of the sedimentary basin, and geometric distribution of the stratigraphic units were based on observations of outcrops and drill core, textural and mineralogic analyses, and descriptions of sedimentologic and pedologic features. The oldest basin-fill unit that crops out near the study area is the Pliocene Fort Hancock Formation. It consists mostly of lacustrine sediments and fine-grained distal alluvial fan sediments in the vicinity of the study area, with coarser alluvial fan sediments closer to the margin of the basin. The overlying Camp Rice Formation consists mostly of sands and gravels deposited by the ancestral Rio Grande and its tributaries.

Structural geologic studies were focused on the Campo Grande fault, the closest known capable fault to the study area. Investigations of scarp morphology, mapping of faults and related units, and descriptions of outcrops and bulldozer excavations were used to estimate recurrence intervals, possible age of last displacement, amount of displacement per event, and the history of faulting. The results of these investigations have been transmitted to the Authority and to seismologists at The University of Texas at El Paso.

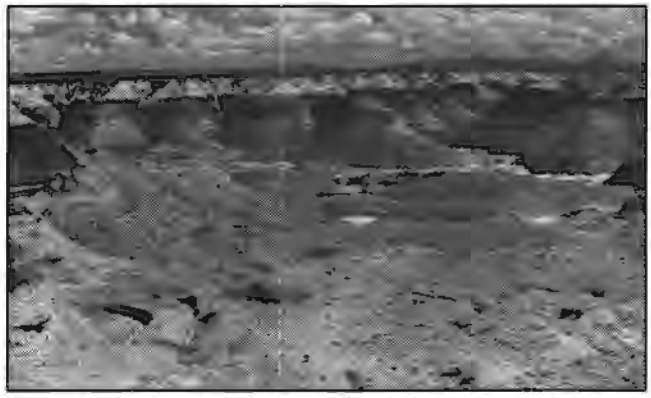
Geomorphic studies have emphasized a description of the development of landforms in the study area and the processes that are or have been active during the Quaternary. Some important findings are that erosion of unconsolidated alluvial fill along tributaries to the major arroyos has occurred about twice as fast as erosion of alluvial fill in valley-side gullies. Locally, fissures have developed in near-surface materials as a result of piping along tension fractures. These and other geomorphic investigations have been closely coordinated with modeling of surface-water flow and studies of the hydrology of the vadose zone. Monitoring of erosion and rainfall is continuing.

Surface-water flow at the study area was investigated as part of the hydrologic studies. The regulatory requirements dictate that the repository should not be located in a 100-year flood plain. Drainage basins and surface-water pathways were identified, and the relation between precipitation and surface-water runoff was quantified and calibrated using field data from meteorologic and stream-gauge instruments. Computer models of streamflow hydrographs and of flood profiles were used to determine the peak surface runoff and flood plain due to actual and hypothetical rain events.

The primary purpose of studies of flow in the unsaturated zone was to evaluate the potential for radionuclide migration by determining the direction and rate of water flow, using physical and chemical methods. Physical methods included monitoring moisture content, water potential, and temperature. Various numerical models were used to simulate isothermal and nonisothermal liquid and vapor transport. Chemical methods included recharge studies based on ionic concentrations of chloride (Cl) and on concentrations of ^{36}Cl and ^{3}H (tritium) isotopes in shallow soil samples.

Preliminary results indicate that moisture movement is restricted to the upper 0.5 m after rainfall events. Monthly monitoring of moisture content shows that recharge pulses are not moving through the system. Water potentials increase with depth, indicating that the main direction of water flow in the unsaturated zone is upward, probably controlled by evapotranspiration. Good agreement was found between observed water potentials and simulated water potentials that were generated with a numerical model based on steady-state upward flow in a layered system. Ionic and isotopic data, however, indicate downward movement of water. Additional studies using stable isotopes were in progress late in 1989 to determine the relative importance of liquid and vapor phase transport.

Characterization of the ground-water flow system focused on evaluating ground-water resources, determining ground-water flow paths and velocities, testing hypotheses using ground-water flow models, and determining ground-water hydrochemistry. Hydrologic investigations of the saturated zone included monitoring water-level fluctuations and determining aquifer properties at wells drilled in the study area and at existing wells in the vicinity. To determine the range of chemical composition of subsurface waters, ground-water and soil-moisture samples were collected and analyzed to expand a data base derived from previous investigations (1986, 1987).



Dark, horizontally bedded lacustrine clays and distal alluvial sands of the upper Tertiary Fort Hancock Formation capped by light-colored Quaternary Madden Gravels of alluvial fan origin (background). These formations are shown in outcrop in Alamo Arroyo, northwest of the proposed site for the Texas repository of low-level radioactive waste in Hudspeth County.

The direction of ground-water flow in the region, interpreted from the potentiometric surface, is generally south-southwest from the Diablo Plateau escarpment toward the Rio Grande. Development of ground-water resources is limited due to the depth (greater than 122 m) and low transmissivities of the aquifer units (4.0×10^{-3} to 2.7×10^{1} m^2/day). The regional aquifer units contain mainly Na-SO_4 ground water; groundwater in alluvium bordering the Rio Grande is dominated by sodium and chloride ions. All ground waters acquire major compositional characteristics early in their flow paths. Ages estimated from tritium and carbon-14 activities show that Rio Grande ground waters are youngest and that ground water from the regional aquifer units ranges from a few hundred to nearly 29,000 yr; the oldest waters occur in wells near the center of the bolson.

Experimental Determination of Hazardous Waste Degradation Reactions during Deep-Well Injection into Saline Formations of the Gulf Coast

Charles W. Kreitler and Regina M. Capuano, principal investigators; assisted by Mark E. Erwin

Over 8.6 billion gallons of liquid hazardous waste are disposed of nationwide by deep-well injection each year. About 90 percent is injected in the Gulf Coast region. Federal legislation (*Federal Register* 40 FR 146) now

limits deep-well injection unless the injector can demonstrate that there will be no migration of hazardous constituents from the injection zone for as long as the waste remains hazardous. This can be accomplished by showing either that the waste will not migrate from the injection zone for 10,000 years or that the wastes will degrade to nontoxic chemicals. Recent investigations by the Bureau have indicated that up to 80 percent of the injected hazardous wastes are organic and can be degraded to nontoxic chemicals by a variety of chemical processes. Biologic degradation may be the most important reaction remediating these hazardous wastes. In a related investigation on the zones used for injection within the Frio Formation of the Texas Gulf Coast, naturally occurring organic material appears to be biodegraded to depths of approximately 7,000 ft. Hazardous organic waste may undergo similar reactions.

This recently initiated program, funded by the Gulf Coast Hazardous Substance Research Center, will be sampling an injection waste plume after the organics have been in the subsurface long enough for potential degradation reactions to have started. We are now evaluating the most suitable chemical composition of a waste stream for sampling and finding an injection facility where samples can be collected from a monitoring well or from back-flushing of the injection well. After an appropriate site has been identified, samples will be collected to determine if degradation is occurring in the subsurface. Detailed sampling will be conducted in the second year of the program.

Ground-Water Studies

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

Alan R. Dutton, principal investigator;
Bernd C. Richter; assisted by John E. Nicol

This study, funded by the Lower Colorado River Authority, was designed to develop a ground-water flow model and procedures for evaluating surface- and ground-water management strategies affecting the Gulf Coast aquifer system in the area between the Lavaca and Brazos Rivers in the Texas Coastal Zone. The study focused on Wharton and Matagorda Counties, Texas, the region that uses the most surface water diverted from the Colorado River for irrigation.

Local geology and hydrology of the Gulf Coast aquifer system largely determine the impacts of water management strategies such as conjunctive use of artificial recharge and surface and ground waters. The hydrogeologic setting was characterized in detail in order to develop a valid conceptual model of ground-water flow in this part of the Gulf Coast aquifer. A quasi-three-dimensional perspective on sand bed, hydraulic head, and hydrochemical facies distributions was constructed extensively using available data manipulated and mapped using RS/1 and CPS-1 software.

The Gulf Coast aquifer in Matagorda and Wharton Counties is made of complex and heterogeneous packages of sand and clay. On the basis of detailed mapping of sand-bed distribution, hydraulic head, and hydrochemical facies in horizontal and vertical planes, it appears that the Pleistocene Beaumont Formation in the study area should be treated as a hydrologic unit distinct from the Chicot aquifer unit.

A conceptual hydrologic model of the Gulf Coast aquifer includes recharge in the outcrop of the aquifer units, downdip flow of ground water, and cross-formational flow directed upward beneath river valleys and in the vicinity of the coastline. Water chemical composition and salinity are controlled by both mineralogic reactions and mixing with seawater. Seawater enters the system both by downward leakage through the Beaumont, which it enters as aerosol or sea spray and during hurricane-driven floods, and by intrusion beneath the coastline driven by differences in fluid density between fresh and salt water. Hydrologic properties of the aquifers are highly variable but can be correlated to patterns in the distribution of sand deposits. Lateral boundaries to the ground-water basins originally were imposed by the valleys of the Lavaca and Navidad Rivers to the southwest and of the Brazos River to the northeast, but enlargement of the cone of depression of the hydraulic-head surface of the Gulf Coast aquifer system in the Harris and Brazoria Counties area has essentially breached the northeastern ground-water basin divide, draining some ground water from the study area off to the northeast.

A numerical model representing the hydrogeologic properties of the study area was constructed and expressed in a 56-row by 50-column by 3-layer grid of blocks. Block-face width varied from 1.5 mi at the center of the study area to 2.5 mi at the edges. A computer program for modeling ground water flow, MODFLOW, developed by the U.S. Geological Survey, was used to quantify the ground-water-flow equation for the large grid of finite-difference blocks. The numerical model was calibrated by matching simulated hydraulic heads against historic head values and then was used to estimate future water-level declines in the Chicot and Evangeline aquifer units. Assuming pumping rates are controlled by high projected demands for water, calculated rates of water-level decline in the Chicot

aquifer unit average 1 ft/yr in 1990 but decrease to approximately 0.2 ft/yr by 2040. The cumulative increase in drawdown of hydraulic head will increase the potential for seawater intrusion and will also further slightly affect land surface subsidence over the region.

Development of an Integrated Hydrogeologic and Hydrochemical Model of the Department of Energy Pleasant Bayou Geopressured-Geothermal Test Well No. 2, Brazoria County, Texas

Charles W. Kreitler, program coordinator; Regina M. Capuano, principal investigator; M. Saleem Akhter; assisted by Mark E. Erwin, Rachel A. Eustice, David A. Lloyd, Jim J. Tubbs, and Vichai Maroongroge

The Department of Energy's geopressured-geothermal test well at Pleasant Bayou in Brazoria County, Texas, has been flow-tested successfully for the last year at brine production rates between 15,000 and 20,000 bbl per day. Relatively small pressure declines (less than 200 psi) have been observed in the reservoir pressure over this period, whereas over 7.1 MMbbl of brine have been produced. The geothermal reservoir now appears to be larger than anticipated. The Bureau has been evaluating the chemistry of the produced water and the pressure declines within the well to determine whether hydrologic boundaries have been reached and whether water from additional sources could be leaking into the reservoir. Most chemical species in the produced water either have remained constant or reflect a very gradual change through the testing period. Analysis of the hydrochemical data does not show sources of brine other than waters from the primary reservoir. Leakage up potential fault zones has not been observed. Production and pressure behavior of surrounding geopressured oil and gas fields is being evaluated to better predict the size and future performance of the Pleasant Bayou geopressured reservoir.

Developing Guidelines for Wellhead Protection Areas in Confined Aquifer Settings

Charles W. Kreitler, principal investigator; Rainer K. Senger; assisted by Kenneth B. Alexander

Much of the ground water of the United States is produced from confined aquifers. The threat of contamination to wells in these aquifers is lessened, although still present, in comparison with water-table aquifers because of its confinement. All public water supply wells, however, need wellhead protection programs. Wellhead protection programs for wells in unconfined aquifers can be established through existing techniques such as calculated or arbitrary fixed radius, simplified variable shapes, analytical solutions, and numerical models. 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 has developed a 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 defines the nature of confinement (unconfined, semiconfined, or confined) and can be accomplished through geologic, hydrologic (pump testing, interpretation of elevation of the potentiometric surface and continuous water-level data, numerical modeling), and geochemical approaches (interpretation of absolute age measurements with radioactive isotopes). The second step delineates the size of the protection area. The approach recommended is to calculate the cone of depression for a producing well field and then calculate a 40-year time-of-travel contour from the hydraulic gradient data. The end product will be a technical manual for state water agencies to use in defining wellhead protection areas for their states.

Identification of Sources of Ground-Water Salinization Using Geochemical Techniques

Charles W. Kreitler, principal investigator; Bernd C. Richter

Sodium chloride has probably contaminated more ground water in the United States than any other contaminant. Contamination results from mixing of fresh water with sodium chloride derived from a variety of sources, including oilfield operations, salt dissolution, sedimentary basin brine discharge, and sea-water intrusion. Oilfield operations have been considered a prime source for contamination. However, multiple sources may exist at the same location. In some contaminated areas, two or more sources may be active, making it more difficult to identify a dominant source. For taking remedial measures, however, it is important not only to detect the contamination but also to document individual sources as accurately as possible.

Geochemical analyses of the brackish contaminated water and the brine sources may permit separation of the different brines and therefore identify the relative importance of different sources. A variety of different methods have been used in the past, including ion ratios such as Na/Cl, Ca/Cl, Mg/Cl, and SO_4, isotopic compositions, and distribution of naturally occurring organic compounds.

This investigation, funded by the U.S. Environmental Protection Agency (EPA), is divided into three major tasks: (1) literature review and compilation of existing data and methodologies; (2) field testing of identified methodologies at five to six sites across the United States; and (3) preparation of a technical manual for the EPA. The duration of the project is 2 years; 1989 was the first year.

A Pilot Geographic Information System for the Edwards Aquifer Recharge Zone, Central Texas

E. G. Wermund, principal investigator

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

The 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. 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, and formatting and input of the tabular and textual data bases are 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. In 1989, an ArcInfo GIS system was selected to complete the work. Use of this system required reformatting previously digitized map data, which is nearly complete.

Coastal Studies

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

William A. White, principal investigator; Thomas R. Calnan, Robert A. Morton, and H. Seay Nance; Barbara M. Hartmann (cartographer)

Work on this long-term, comprehensive inventory of Texas coastal submerged lands and associated wetlands was completed in 1989. Past funding for the project 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 was to produce an extensive data base characterizing submerged lands and wetlands along the entire Texas coast from Sabine Lake to the Rio Grande. To accomplish this objective, the coast was subdivided into seven areas for mapping and reporting purposes. In 1989, publication of atlases covering the Port Lavaca and Kingsville areas completed the series of seven atlases. Previously published atlases include Corpus Christi (the first, published in 1983), Galveston–Houston, Brownsville–Harlingen, Beaumont–Port Arthur, and Bay City–Freeport.

All seven atlases consist of a text and 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.

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. Anomalous occurrences of trace metals have been identified in several areas along the Texas coast; high concentrations in some sediments are apparently related to anthropogenic contributions of trace metals to the system.

Benthic macroinvertebrates found in bay-estuary-lagoon and inner shelf sediments are primarily polychaetes, bivalves, gastropods, and crustaceans. Polychaetes are dominant in most sediments. On the inner shelf, stations having higher percentages of sand generally have more benthic species. This positive correlation between percent sand and number of species is lower in the bays than on the inner shelf. 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. Cluster analysis of data from stations in the bay-estuary-lagoon system generally yielded less-defined station groupings and assemblages than that of data from stations on the inner shelf. This was expected because of greater hydrographic and sediment variability in the bays.

One objective of the study was 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. Comparisons of the distribution of wetlands mapped on photographs taken primarily in 1979 as part of the submerged lands project with wetlands mapped on mid-1950's photographs as part of the Environmental Geologic Atlas project reveal wetland changes in many areas along the Texas coast. The most extensive changes were found in the Galveston–Houston and Beaumont–Port Arthur areas. Many changes, which include the replacement of marshes by open water, are related to land-surface subsidence and surface faulting.

The Submerged Lands of Texas project has spanned many years and research phases and involved many participants. Numerous Bureau staff members have provided the dedicated support required to complete such a comprehensive, multiphased investigation culminating in the publication of seven atlases, each composed of detailed narrative reports, appendices, and maps. The authors are indebted to these individuals.

Sedimentation in Fluvial-Deltaic Wetlands and Estuarine Areas, Texas Gulf Coast

William A. White and Thomas R. Calnan, principal investigators; Richard D. Edson, Jr., Steven W. Tweedy, George T. Bush, and Richard Goldsmith

Funding for this project was provided through interagency cooperation agreements with the Texas Parks and Wildlife Department with funds made available by the Texas Water Development Board through the Board's Water Reseach and Planning Fund. This project addresses fluvial-deltaic wetland and estuarine sedimentation and associated interactive processes along the Texas Gulf coast through (1) a literature review and synthesis, (2) field investigations, and (3) historical analyses of wetland changes in fluvial-deltaic areas. This investigation was conducted from December 1987 to August 31, 1989.

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. Among the interactive processes that were analyzed are riverine discharge and associated sediment loads, subsidence and relative sea-level rise, deltaic and estuarine sedimentation rates, marsh aggradation rates, biodeposition, and human activities.

In the field investigation, salt-water marshes on the Colorado River delta and brackish-water marshes on the Trinity River delta were monitored over a period of 15 to 24 months to document sediment accumulation rates. Vegetation types, vegetation heights, elevations,

Bureau researcher conducting an elevation survey of a brackish-water marsh on the Trinity River delta, Chambers County, Texas. This data-gathering is designed to help determine historical land loss or gain, sedimentation rates, and changes in emergent vegetation in major fluvial-deltaic areas along the Texas Gulf Coast.

and sediment composition were among the other types of information collected during periodic surveys. Short-term marsh sedimentation rates were determined primarily by using artificial-marker horizons established at selected sites along marsh transects. Initially, eleven markers were placed in wetlands in the Trinity River delta study area, and nine in the Colorado River delta study area. Longer-term sedimentation rates were determined by radiochemically dating sediments (using ^{210}Pb) in cores taken from marsh substrates.

The principal focus of the historical investigation was to document changes in emergent vegetation in fluvial-deltaic wetlands to determine the extent to which the vegetated areas are being replaced by open water or barren flats. Seven rivers were selected for the historical analysis: Colorado, Guadalupe, Lavaca, Neches, Nueces, San Jacinto, and Trinity. Vegetated wetlands and water/barren flats were mapped on sequential aerial photographs dating from the 1930's to the late 1970's or 1980's. Units delineated on aerial photographs were digitized, plotted on maps, and their areal distribution computed and graphed to determine trends and magnitudes of historical changes.

Marsh aggradation rates in the Colorado River delta are similar to those in salt marshes reported for other areas of the Gulf Coast. The highest rates (9 to about than 12 mm/yr) in the Colorado River delta occur 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. During the first year of investigation, sediment deposition on higher levee marshes was insignificant (<1 mm/yr) because no floods sufficient to inundate these marshes had occurred. However, landfall of Hurricane Gilbert in September 1988 shifted depositional patterns and accounted for as much as 80 percent of the total sediment accumulation at one levee site and an average of about 60 percent of the total at other sites for the monitoring period. Rates of marsh aggradation in the Trinity River delta were more variable and less predictable than those of the Colorado River delta. Over the first year of study, short-term rates varied from 0 (erosion) to more than 12 mm/yr, with one anomalous site of 39 mm/yr. During the second year, near-record flooding along the Trinity River had a significant effect on wetland sedimentation, as exemplified in a levee site along the river where more than 50 mm of deposition occurred, apparently during the major flood event.

Deposition and erosion patterns in both the Colorado and Trinity River deltas indicated seasonal variations. Maximum deposition occurred from spring to fall, when marsh aggradation was punctuated by hurricanes and/or river flood events. Minimal deposition, and locally erosion, occurred during winter months, when storms affected marsh environments, particularly in delta-front areas. Long-term sedimentation rates determined from ^{210}Pb analyses of cores collected in backmarsh areas show that rates are higher in the Colorado River delta, where the average rate is 7.5 mm/yr, than in the Trinity River delta, where the average is 5.4 mm/yr. These differences are supported by historical analyses that show marsh deterioration and loss (overall) in the Trinity delta and gains in marsh area in the Colorado delta since the mid-1950's.

In the Colorado River delta study area, both intertidal and higher marshes located near sand-rich Matagorda Peninsula were predictably high in sand (concentrations near 80 percent). In the Trinity delta study area, marsh sediments near the bay margins and levees were rich in sand and/or silt. Clay was most abundant in low-energy backmarsh environments. Organics were a more significant component of the marsh sediments in the brackish-water marshes of the Trinity River delta than in the salt-water marshes of the Colorado River delta. A seasonal change in vegetation type and cover is a significant process in some brackish marsh areas in the Trinity River delta and can affect organic and inorganic erosion, transportation, and deposition.

Results of historical analyses of wetlands in fluvial-deltaic and associated alluvial valley regions indicate that emergent vegetation is being replaced by water and barren flats. Magnitude of replacement in the different regions varies from less than 5 percent to about 50 percent of the mapped areas for the period of analysis (generally from the mid 1930's to 1979 or later). The Colorado River delta, although losing emergent vegetation in parts of the delta, is the only one of the seven areas analyzed that, as a whole, has increased in total vegetated area since the mid-1950's. In other fluvial-deltaic areas, there is little evidence to suggest a reversal in loss of vegetated wetlands.

Historical Shoreline Changes in Copano, Aransas, and Redfish Bays, Texas Gulf Coast

Robert A. Morton, principal investigator; Jeffrey G. Paine

As more people and industries migrate to the Texas Coastal Zone, both the human and the economic impacts of pervasive coastal erosion become more acute. This erosion, whether caused in a moment by hurricanes or over the years by everyday waves, is common to Texas gulf and bay shorelines. After a report on recent gulf shoreline and vegetation-line movement was completed early in 1989, historical monitoring efforts turned to the Copano Bay system, including Copano, Aransas, and Redfish Bays.

Common shoreline types in the Copano Bay system include low deltaic and bay-margin marshes, sandy slopes of a late Pleistocene strandline, clay bluffs formed by upper Pleistocene fluvial and deltaic sediments, and made land. Movement along bay shorelines, determined from aerial photographs dating from the early 1930's, the late 1950's, and the 1980's, is generally slower than movement along gulf shorelines because wave energy is lower, the tide range is less, and less sediment is transported by the littoral system. Nevertheless, significant shoreline movement has occurred in the past and continues today. Investigations of shoreline movement in the Copano Bay system were completed in late 1989. A report summarizing these changes will follow the same format as that in published Bureau studies of the Galveston, Matagorda, San Antonio, and Corpus Christi Bay systems.

Assessment of the Sand Resources of Heald and Sabine Banks, Texas Exclusive Economic Zone

Jules R. DuBar, principal investigator;
Jeffrey G. Paine

A recent assessment of nonfuel minerals on the Texas continental shelf demonstrated that insufficient geological and geophysical data exist to locate and quantitatively characterize many of the potentially economic deposits. These deposits, including sand, gravel, and heavy mineral placers, will probably not be economic in the near future, but specific deposits may become economic at any time. Most promising are offshore sands suitable for beach nourishment because sand size requirements for these projects are strict, on-land sources are limited, and expensive overland transport can be avoided. Demand for compatible sand for public and private beach nourishment along the Texas coast is increasing as the combined effects of rising sea level, land subsidence, decreasing river sediment, and coastal compartmentalization are reflected in widespread beach erosion. Consequently, there is interest in finding sand deposits that are (1) located in the Texas Exclusive Economic Zone, (2) relatively close to potential markets in Texas and Louisiana, and (3) suitable for beach nourishment. Heald and Sabine Banks, interpreted as submerged shoreline or shallow marine sands, meet these criteria.

The purpose of the three-year project, funded by the U.S. Bureau of Mines through the Marine Minerals Technology Center, is to assess the volume and quality of Heald and Sabine Bank sediments for use in beach nourishment projects such as those considered for the eastern Texas and western Louisiana coasts. To accomplish this, a part of the banks will be surveyed with high-resolution seismic equipment and cored to obtain samples for textural, chemical, and paleoenvironmental analyses. First-year work, which began in October 1989, includes collection of available core and geophysical data and completion of a high-resolution seismic survey of the banks.

Monitoring the Beach and Vegetation Line on Galveston Island

Robert A. Morton, principal investigator;
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 in part 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, and Follets Island.

Results of the field work more than 6 years after Hurricane Alicia show that dunes are reforming in undeveloped areas but not in developed areas; furthermore, the backbeach elevation of West Beach is still lower than it was before the storm. Significant dune construction, backbeach aggradation, and shoreline stabilization on northeastern Follets Island indicate that most of the sand permanently removed from Galveston Island by Hurricane Alicia was transported southwestward by strong nearshore currents.

Coastal Mapping and Shoreline Monitoring Projects

Robert A. Morton, principal investigator;
Jeffrey G. Paine

During 1989, the Bureau conducted three minor studies of coastal beaches and barrier islands. One study, funded by the South Texas Barrier Island Task Force, analyzed the flooding and washover potential of Mustang Island and North Padre Island. The objective was to identify historical storm washover channels and to evaluate the potential for dune erosion during major hurricanes. These hurricane hazard zones are assigned high risks on flood-potential maps because they represent areas subjected to abnormally high waves and current

velocities. Maps of the hurricane hazard zones were prepared after examining recent post-storm aerial photographs, topographic maps, and ground surveys.

A second study, designed to assist the Coastal Division of the Texas General Land Office, also involved the Mustang–North Padre Island area. This study investigated the possible physical effects of reopening a former tidal inlet (Packery Channel) that connected Laguna Madre and the Gulf of Mexico. Of particular interest is the potential for increased flooding of nearby areas due to severe hurricanes, erosion of adjacent beaches, siltation within the dredged channel, and circulation changes within Laguna Madre and Corpus Christi Bay. A report on possible impacts was prepared.

The third study was conducted in cooperation with the Galveston District Corps of Engineers. It focused on the rapidly accelerating erosion of the Gulf shoreline near Sargent Beach, Texas. The primary purpose of the work was to predict the position of the Gulf shoreline in the years 2000 and 2050. This was accomplished by mapping shoreline position on aerial photographs and analyzing the historical rates of erosion and volumetric land losses for several periods between 1853 and 1987. Plots of cumulative erosion versus time and volumetric losses versus time were used to project the most recent erosion trends. These erosion rates, derived from aerial photographs, were comparable to those derived from ground surveys between 1970 and 1989.

Decline of Submerged Vegetation in the Galveston Bay System: Chronology and Relationships to Physical Processes

William A. White and Warren M. Pulich (Texas Parks and Wildlife Department), principal investigators

This study was funded through interagency agreements with the Texas Parks and Wildlife Department (TPWD) and Texas Water Development Board. The objective of the project was to examine the potential causes of extensive losses of submerged vegetation in the Galveston–Trinity Bay system during the past 30 yr. The disappearance of this valuable subtidal habitat has received widespread attention with the recent designation of Galveston Bay as a national estuary by the EPA National Estuary Program. Historical review of the chronological sequence of submerged-vegetation habitat loss has been especially recommended to help determine critical factors threatening estuarine plants and to properly design management solutions aimed at restoring impacted submerged-vegetation habitat.

Major regions of the Galveston Bay system where submerged vegetation has declined since the 1950's were compared with the few nearby remaining sites where vegetation still persists. This approach involved compilation and analysis of active processes and hydrological data, which could affect distribution and abundance of rooted estuarine plants. Distribution of submerged vegetation during different time periods was mapped, and physical/hydrological factors were correlated with vegetation changes in an attempt to establish the processes contributing to impacts on these productive habitats.

Current locations of submerged vegetation were determined from November 1987 NASA-Ames color-infrared aerial photographs and corroborated by field investigations in 1988-89. This survey delineated submerged vegetation in two general regions of the bay: (1) along the northern and eastern shores of the upper bay (Trinity Bay) and (2) in the Christmas–Drum Bay area of the lower (West Bay) system. This late 1980's distribution was contrasted with historical distribution of adjacent or nearby locations in the upper bay along the Clear Lake–Seabrook shoreline, and in lower West Bay along the Galveston Island shoreline. Occurrence of submerged vegetation in these areas formerly was established from project reports of TPWD biologists, conversations with knowledgeable field biologists and fishermen, and review of archived aerial photographs. From this investigation, the chronology of submerged vegetation decline and disappearance could be documented from the late 1950's.

Submerged vegetation acreage was mapped at a scale of 1:24,000 on USGS quadrangle sheets. Changes in acreage were calculated from 1:24,000 base map overlays for the years 1956 and 1962 for Seabrook in upper (Trinity) bay and for the years 1956, 1965, 1975, and 1987 in the lower bay area. Disturbance features (residential developments, dredged channels, boat marinas) were also mapped in portions of West Bay.

For these defined submerged vegetation sites, historical data on various physical/hydrological processes affecting the bay environment were compiled and reviewed. These included the following factors known to affect growth of submerged vegetation: shoreline erosion and relative sea-level rise associated with compactional subsidence; hurricane and other climatic events; physical alterations related to channel dredging and residential developments; and degradation in selected water quality conditions. A number of state agency data bases were examined for this study: Bureau of Economic Geology Environmental Geologic Atlas and shoreline erosion data; TPWD Coastal Resource Monitoring Program water quality data; Texas Water Commission wastewater discharge permits records; and TPWD fish kill/pollution monitoring reports. Results of the study were presented at the 10th Biennial International Estuarine Research Federation Conference in Baltimore, Maryland.

Mineral Resources Investigations

Igneous Petrogenesis and Ore Deposition, Trans-Pecos Texas

Christopher D. Henry, principal investigator; Eric W. James

This project, funded by the U.S. Bureau of Mines under a grant to the Texas Mining and Mineral Resources Research Institute, is examining the relationship between igneous activity and ore formation. Igneous magmas may supply both the metals that form an ore body and the heat and fluids that transport and concentrate the metals. Research this year focused on ore deposits and areas of hydrothermal alteration in Trans-Pecos Texas using field mapping, geochemical analyses of rocks and minerals, detailed petrography, potassium-argon dating, and computer modeling of thermodynamic and hydrothermal processes. Areas studied include (1) the Sierra Blanca intrusions, which have major beryllium deposits, (2) the Infiernito caldera, which has silver and molybdenum prospects, (3) the Christmas Mountains intrusive province, which has trace-element-enriched fluorite deposits, and (4) other trace-element-enriched intrusions in southern Trans-Pecos Texas.

Research on the Sierra Blanca beryllium-fluorite deposits has been in collaboration with Cyprus Beryllium Company. Geochemical analyses of the Sierra Blanca rhyolites demonstrate that they are enriched in beryllium and fluorine and undoubtedly were the source of these elements in the deposits. The analyses also show that the rhyolites are highly enriched in rare-earth elements, some of which may occur in potentially economic concentrations. Mineral separates of the igneous rocks have been prepared for isotopic study to determine the origin of the rocks and ultimately of the beryllium and other enriched elements.

Research on the Infiernito caldera includes geologic mapping of the entire structure, determination of the volcanic and intrusive history of the caldera, study of the geochemical evolution of the caldera, identification of areas of hydrothermal alteration and mineral prospects, and determination of the igneous and structural setting of mineralization. Mapping will be completed in 1990. A Report of Investigations detailing the geology and ore deposit potential of the caldera and including a 1:24,000-scale geologic map will be prepared at that time.

Research on the Christmas Mountains intrusive province and its many trace-element-enriched fluorite deposits is currently focused on the geochemistry of the intrusions and deposits. The basic mapping is complete; a geologic map and extensive report were published in 1989 as Report of Investigations No. 183.

Research on the peralkaline rhyolites of southern Trans-Pecos Texas is a followup to the Sierra Blanca and Christmas Mountains work. These rhyolites are also enriched in fluorine, beryllium, molybdenum, thorium, and uranium. Fluorite deposits associated with some of the intrusions are irregularly enriched in the trace elements. Representative samples of nearly all the intrusions and of many fluorite deposits have been collected. Chemical and mineralogical analysis is underway.

Mineral Resource Assessment, Big Bend Ranch State Natural Area, Presidio and Brewster Counties, Texas

Christopher D. Henry and Jay A. Raney, principal investigators; Jeffrey N. Rubin and Allan R. Standen

The Bureau of Economic Geology investigated the mineral resources of the newly established Big Bend Ranch State Natural Area for the Texas Parks and Wildlife Department and the General Land Office. The area exhibits a diverse geology reflecting nearly 600 million years of geologic evolution. Major geologic events include (1) deposition of clastic sedimentary rocks during the Paleozoic and their deformation (folding and faulting) at the end of the Paleozoic, (2) deposition of limestone and clastic rocks during the Cretaceous and their deformation during the early Tertiary, (3) intense extrusive and intrusive igneous activity during the middle Tertiary, and (4) major normal faulting during the late Tertiary.

Almost all mineral potential of the area is associated with mid-Tertiary igneous activity. The only significant mineral production within the Ranch area was from the Fresno mine in the western part of the Terlingua mercury district, one of the largest mining districts in Texas. This mine produced approximately 3,500 flasks of mercury, mostly during World War II.

The eastern part of the Ranch has the greatest potential for economic mineral deposits. Areas along the Terlingua monocline, the site of the Fresno mine, and within Contrabando dome, are prospective for mercury and possibly for precious metals (silver, gold). The Solitario, an igneous dome mantled by Cretaceous and Paleozoic sedimentary rocks, has numerous prospects and areas of hydrothermal alteration. The extent of the alteration and geochemical anomalies indicates significant potential for precious and base (molybdenum,

lead, zinc, copper) metal deposits. More speculative mineral potential includes that of (1) rare metals, particularly beryllium, associated with several peralkaline rhyolite intrusions and (2) zeolite (clinoptilolite) found in tuffaceous sediments.

Texas Portland Cement Industry and Cement Resources

Mary W. McBride, principal investigator; Tom S. Patty (consultant, Erlin Hime Associates, Austin, Texas), and Roger D. Sharpe (USG Corporation, Chicago, Illinois)

Texas has been a major cement-producing state for over a hundred years. A draft report describing the importance of the industry and Texas' vast supply of raw materials needed for the manufacture of cement was submitted for publication in 1989.

The objective of the report is to increase the layperson's appreciation of the contributions and problems of this industry as well as to provide to those in the cement industry an inventory of the Texas resource base of cement raw materials. The report traces, primarily through data from the U.S. Bureau of Mines, the production growth and problems of the Texas industry through the high-demand years of the late 1970's and early 1980's and the years of decreasing production since 1984. Information regarding potential and currently used resource materials is summarized by commodity from data collected from Bureau files.

Industrial Minerals of Texas

L. Edwin Garner, principal investigator

The Texas Dimension Stone Industry and the Texas Aggregate Industry projects, both funded by 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 relationship of statewide production to U.S. 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. A draft manuscript was prepared at yearend.

Texas Mining and Mineral Resources Research Institute

Christopher D. Henry, 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 and two members of the Texas mining industry serve on the TMMRRI Fellowship Committee. For the 1989–90 academic year, three fellowships were awarded to support graduate research in ore deposition, rock mechanics, and petroleum recovery. In addition, three graduate students received support in 1988–89 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, principal investigator

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, principal investigator; Dan F. Scranton, Barbara M. Hartmann, cartographers

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), principal investigator; 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 tectonic map of Texas, incorporating 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 in the Davis Mountains, Trans-Pecos Texas

Christopher D. Henry, principal investigator; Jeffrey N. Rubin, and Heng Tsai; Mick Kunk and John Sutter (U.S. Geological Survey, Reston, Virginia)

Geologic mapping of the volcanic rocks of the Davis Mountains began in 1987 as a multiyear project, funded by the U.S. Geological Survey's Cooperative Geologic Mapping Program (COGEOMAP). The first phase of the COGEOMAP project, mapping in the Christmas and Hen Egg Mountains, was completed in 1988, culminating in a report and a full-color 1:24,000-scale geologic map published in 1989 (Report of Investigations No. 183).

The Davis Mountains constitute a major part of the Trans-Pecos volcanic field. Nevertheless, because of the volcanic and stratigraphic complexity, the area remains the most poorly mapped and least understood part of the field. Mapping for this project began in the eastern and southeastern parts of the Davis Mountains and has progressed toward the southwest. Mapping involved extensive field work, analysis of 1:24,000 color and black-and-white aerial photographs, geochemical analysis, and isotopic dating by the $^{40}Ar/^{39}Ar$ method. The work to date has substantially revised previous interpretations. Several previously unrecognized volcanic units have been identified. Additionally, many existing formations that included a wide range of unrelated volcanic rocks have been subdivided into genetically related packages. The mapping has identified several unusual types of volcanic rocks, particularly large-volume, extensive silicic rocks that have the outcrop characteristics of lavas but the areal extents of ash-flow tuffs. Some of these are rheomorphic ash-flow tuffs, which underwent secondary laminar viscous flow following tuffaceous deposition. Others are true silicic lavas that are far more extensive than any previously recognized. High-precision isotopic dating reveals that volcanic activity in the Davis Mountains studied so far occurred between 36.8 and 35.3 Ma in five distinct intervals.

Other Geologic Investigations

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

L. F. Brown, Jr., principal investigator

In 1989 a manuscript titled "Regional Depositional Systems Tracts, Paleogeography, and Sequence Stratigraphy, Upper Pennsylvanian and Lower Permian Strata, North-Central Texas" was submitted for publication. This report, the culmination of many years of research on cyclothemic sequences, integrates 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 series of cross sections 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.

Mined Lands Inventory, Industrial Minerals, South and East Texas

William R. Kaiser, principal investigator;
L. Edwin Garner and Mary L. W. Jackson;
assisted by Mark W. Andreason,
Robert H. Blodgett, Michelle M. Mallien,
Laura L. Moffett

This project, funded by the Surface Mining and Reclamation Division of the Railroad Commission of Texas, was begun in June 1988 to inventory abandoned and active mines across South and East Texas. Mined sites close to highways and residences are potential accident sites, as shown by the Alton school-bus accident that occurred in 1989. Project objectives are to identify abandoned mines for possible reclamation (priority sites) that threaten health and safety, to create a surface-mining data base for industrial minerals, and to provide data to meet future legislative and regulatory needs. The South Texas phase of the study was completed in September and covers a 48-county area south of the Colorado River and south of the Balcones Escarpment. Work has begun on the evaluation of mining activity in East Texas, an 84-county area north of the Colorado River and east of the Balcones Escarpment.

Comprehensive procedures were established for identification and evaluation of mined lands using U.S. Geological Survey 7.5-minute topographic maps, black-and-white and color-infrared aerial photographs, on-site surveys, and low-altitude flyovers. The site location, mineral commodity, and relative size were recorded on a Mined Lands Inventory Form (MLIF) for each site greater than 2 acres in size. Data on health, safety, and environmental aspects were recorded for all priority sites. Priority sites are identified on the basis of size, presence of a highwall or wetland, proximity to public roads and populated areas, and surrounding urban land use. All data are entered into the Texas Mined Lands Data Base (TMLDB), a computer data base that follows the format of the MLIF. Locations of all inventoried sites are shown on topographic maps.

In South Texas, 4,735 mined sites were identified, 2,839 of which are greater than 2 acres in size, 1,878 less than 2 acres, and 18 of undetermined size. Among the sites larger than 2 acres, 1,328 are abandoned, 1,198 are active, and 313 are reclaimed (naturally or artificially). Approximately 100,000 acres have been disturbed by surface mining; about 70,000 acres were disturbed by sand and gravel mining, 15,000 acres by caliche mining, and 8,000 acres by limestone quarrying.

Bexar, Colorado, De Witt, Victoria, and Travis Counties contain 43 percent of the sites larger than 2 acres. Colorado, De Witt, and Victoria contain dominantly sand and gravel pits, whereas Bexar and Travis contain both sand and gravel pits and limestone quarries. De Witt and Colorado contain the most abandoned mined sites and Bexar and Karnes the most active sites. Few mined sites occur in coastal counties north of the Rio Grande Valley. Priority sites (93) occur in 18 South Texas counties, the largest number (27) being in Colorado County; relatively few priority sites are located in metropolitan areas.

The final contract report on mined lands in South Texas, submitted to the Railroad Commission in 1989, contains a description of project methodology, regional and county maps showing mined sites by status, commodity, and size, and summary statistics on mined lands. Included as appendices are the TMLDB in electronic form and accompanying explanatory manual and 417 topographic maps showing locations of all inventoried sites and priority site ownership. These materials are on open file at the Bureau and Railroad Commission.

Clay Diagenesis in Evaporite Environments, Texas Panhandle

R. Stephen Fisher, principal investigator

The Texas Higher Education Coordinating Board funded this two-year investigation of the type and extent of clay diagenesis that occurs in hypersaline marine evaporite brines. Major goals of the research are (1) to determine the primary and diagenetic composition of detrital silicate minerals from strata below, within, and above thick-bedded Permian evaporites of the Palo Duro Basin, Texas Panhandle, (2) to evaluate the usefulness of clay minerals as indicators of former geochemical conditions, (3) to investigate the mechanisms of clay alteration through laboratory simulation of natural diagenetic reactions between clay minerals and seawater or brine solutions, and (4) to use geochemical modeling methods to establish the thermodynamic properties of authigenic clay minerals and the chemical conditions required for clay alteration in brines of high ionic strength.

During the first year of the study, clay minerals from Pennsylvanian to Permian host rocks were separated and analyzed to establish mineralogic changes as environmental conditions progressed from normal marine to marine evaporite. X-ray diffraction analysis of clays from bedded halite and stratigraphically equivalent salt dissolution zones confirmed that clay minerals can be useful records of paleoenvironmental conditions. Electron microprobe analyses show that plagioclase feldspars become less abundant, and potassium feldspars become more nearly stoichiometric, as geochemical conditions become more saline. Also during the first year of the study, reference clay materials were obtained for the laboratory experiments. These clays were structurally and chemically characterized, and several trial runs of the experiment were conducted to refine laboratory procedures and to standardize analytical methods.

Laboratory experiments now in progress will be completed in early 1990, the second year of the study. The mineralogy of reference clay minerals and altered clay products, the chemical composition of the solutions used in the experiments, and analyses of natural marine evaporite brines and associated clay minerals will be used to constrain thermodynamic parameters input to the geochemical models. Anticipated results of this work include a better understanding of the behavior of clay minerals in natural environments and an improved ability to predict the type of clay mineral present in sandstone reservoirs or aquifers.

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., Ambrose, W. A., Swartz, T. E., **Laubach, S. E.,** Tremain, C. M., and Whitehead, N. H., III, 1989, Geologic evaluation of critical production parameters for coalbed methane resources: San Juan Basin: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Gas Research Institute, under contract no. 5087-214-1544, 171 p.

Brashear, J., Bekker, A., **Ambrose, W. A., Holtz, M.,** and **Tyler, N.,** 1989, Production potential of unrecovered mobile oil through infield development: integrated geologic and engineering studies – overview: ICF Resources, Incorporated, and The University of Texas at Austin, Bureau of Economic Geology, contract report prepared for the U.S. Department of Energy, Office of Fossil Energy, 73 p., plus appendices.

Brashear, J., Bekker, A., **Holtz, M.,** and **Tyler, N.,** 1989, Producing unrecovered mobile oil: evaluation of potential economically recoverable reserves in Texas, Oklahoma, and New Mexico: ICF Resources, Incorporated, and The University of Texas at Austin, Bureau of Economic Geology, contract report prepared for the U.S. Department of Energy, Office of Fossil Energy and Bartlesville Project Office, 78 p., plus appendices.

Brashear, J., Godec, A., Bekker, A., **Ambrose, W. A.,** and **Tyler, N.,** 1989, An assessment of the reserve growth potential of the Frio Barrier-Strandplain play in Texas: ICF-Lewin Energy Division, ICF, Incorporated, and The University of Texas at Austin, Bureau of Economic Geology, contract report prepared for the U.S. Department of Energy, Office of Fossil Energy, 128 p.

Capuano, R. M., and **Kreitler, C. W.,** 1989, Deep well injection: chemical wastes disposed and their subsurface reactions: The University of Texas at Austin, Bureau of Economic Geology, report prepared for U.S. Environmental Protection Agency, Office of Drinking Water, under cooperative agreement no. CR-814056-01-0, 169 p.

Capuano, R. M., and **Kreitler, C. W.,** 1989, Deep well injection: chemical wastes disposed and their subsurface reactions: The University of Texas at Austin, Bureau of Economic Geology, project summary prepared for U.S. Environmental Protection Agency, Office of Drinking Water, under cooperative agreement no. CR-814056-01-0, 18 p.

Garner, L. E., and **DuBar, J. R.,** 1989, Paleontologic survey of the Superconducting Super Collider site: The University of Texas at Austin, Bureau of Economic Geology, prepared for Texas National Research Laboratory Commission under contract no. IAC (90-91)-0381, 172 p.

Henry, C. D., 1989, Volcanic geology of the Davis Mountains, Trans-Pecos Texas: second-year report: The University of Texas at Austin, Bureau of Economic Geology, report prepared for the U.S. Geological Survey under cooperative agreement no. 14-08-0001-A0538, 40 p.

Henry, C. D., Raney, J. A., Rubin, J. N., and **Standen, A. R.,** 1989, Mineral resource assessment, Big Bend Ranch State Natural Area, Presidio and Brewster Counties, Texas: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for Texas Parks and Wildlife Department, contract no. IAC(88-89)-1508, 77 p.

Jackson, M. L. W., Blodgett, R. H., and **Kaiser, W. R.,** 1989, Mined lands inventory, industrial minerals, South Texas: The University of Texas at Austin, Bureau of Economic Geology, contract report prepared for the Railroad Commission of Texas, Surface Mining and Reclamation Division, under interagency cooperation contract no. IAC (88-89)-0979, 31 p.

Jirik, L. A., Ambrose, W. A., Kerr, D. R., and Light, M. P. R., 1989, Coordination of geological and engineering research in support of the Gulf Coast Co-Production Program: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Gas Research Institute under contract no. 5084-212-0924, 118 p.

Kerans, Charles, Lucia, F. J., and **Fogg, G. E.,** 1989, San Andres/Grayburg reservoir characterization research laboratory: progress report, year one, 1988/89: The University of Texas at Austin, Bureau of Economic Geology, contract report, 26 p.

Kreitler, C. W., Senger, R. K., and **Gustavson, T. C.,** 1989, Geologic and hydrologic investigations, Reese Air Force Base, Lubbock, Texas: The University of Texas at Austin, Bureau of Economic Geology, report prepared for U.S. Army Corps of Engineers under contract no. DACA56-88-M-0153, 65 p.

Light, M. P. R., and **Hamlin, H. S.,** 1989, Consolidation of geologic studies of geopressured-geothermal resources in Texas: The University of Texas at Austin, Bureau of Economic Geology, 1987 annual report prepared for the U.S. Department of Energy, Advanced Technologies Division, under contract no. DE-FC07-85NV10412, 28 p.

Milling, M. E., 1989, Major program elements for an advanced geoscience oil and gas recovery research initiative, program study summary report: recommendations and research activities priorities: The University of Texas at Austin, Geoscience Institute for Oil and Gas Recovery Research, report prepared on behalf of Office of Fossil Energy, U.S. Department of Energy, 78 p.

Morton, R. A., 1989, Analysis of shoreline erosion at Sargent Beach, Texas, and projection of shoreline positions in the years 2000 and 2050: The University of Texas at Austin, Bureau of Economic Geology, report prepared for Department of Army, Galveston District, Corps of Engineers, Galveston, Texas, 15 p.

Morton, R. A., 1989, Geological review of documents pertaining to the reopening of Packery Channel, North Padre Island, Texas: The University of Texas at Austin, Bureau of Economic Geology, report prepared for the Texas General Land Office under interagency contract no. IAC(88-89)-1578, 13 p.

Morton, R. A., Sams, R. H., and **Jirik, L. A.,** 1989, Plio-Pleistocene depositional sequences of the southeastern Texas continental shelf and slope: geologic framework, sedimentary facies, and hydrocarbon distribution: The University of Texas at Austin, Bureau of Economic Geology, report supported by CNG Producing, Inc., Louisiana Land and Exploration, Mobil, Pennzoil, Standard Oil, Tenneco, Texaco, and Total-Minatome, 108 p.

Paine, J. G., and **Morton, R. A.,** 1989, Hurricane washover channels between Padre Island National Seashore and the Port Aransas jetties, Kleberg and Nueces Counties, Texas: The University of Texas at Austin, Bureau of Economic Geology, report prepared for the South Texas Barrier Island Task Force, 6 p.

Tye, R. S., 1989, Stratigraphy and depositional systems of the Lower Cretaceous Travis Peak Formation, East Texas Basin: The University of Texas at Austin, Bureau of Economic Geology, topical report prepared for the Gas Research Institute under contract no. 5082-211-0708, 80 p.

The following Bureau publications served as final contract reports during 1989:

Henry, C. D., Price, J. G., and Miser, D. E., 1989, Geology and Tertiary igneous activity of the Hen Egg Mountain and Christmas Mountains quadrangles, Big Bend Region, Trans-Pecos Texas, 105 p.

Funding was provided by the U.S. Geological Survey and by the Texas Mining and Mineral Resources Research Institute.

White, W. A., Calnan, T. R., Morton, R. A., Kimble, R. S., Littleton, T. G., McGowen, J. H., and **Nance, H. S.,** 1989, Submerged lands of Texas, Kingsville area: sediments, geochemistry, benthic macro-invertebrates, and associated wetlands: The University of Texas at Austin, Bureau of Economic Geology Special Publication, 137 p.

White, W. A., Calnan, T. R., Morton, R. A., Kimble, R. S., Littleton, T. G., McGowen, J. H., and **Nance, H. S.,** 1989, Submerged lands of Texas, Port Lavaca area: sediments, geochemistry, benthic macro-invertebrates, and associated wetlands: The University of Texas at Austin, Bureau of Economic Geology Special Publication, 165 p.

Financial assistance for both volumes 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 1989, the following 70 contracts, each of which had reporting requirements, were active at the Bureau:

Federal

"Annex I to the Agreement 'Relating to Fossil Energy Resource Characterization, Research, Technology Development and Technology Transfer'": supported by the U.S. Department of Energy through the Office of the Governor.

"Assessment of the Sand Resources of Heald and Sabine Banks, Texas Exclusive Economic Zone": supported by the Marine Minerals Technology Center, University of Mississippi.

"Characterization of Facies and Permeability Patterns in Carbonate Reservoirs Based on Outcrop Analogs": supported by the U.S. Department of Energy.

"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.

"Computerized Calculation of Lignite Resources, Jackson and Wilcox Trends, South 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 Settings": 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.

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

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

"Identification of Sources of Ground-Water Salinization Using Geochemical Techniques": supported by the U.S. Environmental Protection Agency.

"Mapping Volcanic Centers in the Davis Mountains, Trans-Pecos Magmatic Province (FY89 and FY90)": supported by the U.S. Geological Survey, U.S. Department of the Interior (two contracts).

"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 7)": supported by the Minerals Management Service, U.S. Department of the Interior (six contracts).

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

"Update Current Data on Sargent Beach": supported by the U.S. Army Engineer District, Galveston.

State

"Accurate Modeling of Fluid Flow in Hydrocarbon Reservoirs and Aquifers with Scale Averaged Rock Properties": supported by the Texas Higher Education Coordinating Board.

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

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

"Clay Diagenesis in Evaporite Environments": supported by the Texas Higher Education Coordinating Board.

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

"Edwards Aquifer Committee": supported by the Texas Water Development Board.

"Experimental Determination of Hazardous Waste Degradation Reactions during Deep-Well Injection into Saline Formations of the Gulf Coast": supported by Lamar University.

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

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

"Gas Saturation as a Limit on Pore-Fluid Composition and Diagenetic Alteration in Deep Sedimentary Environments": supported by the Texas Higher Education Coordinating Board.

"Geological Support of Cross-hole Tomography": supported by the University of Houston.

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

"Geologic and Hydrologic Studies Near Fort Hancock, 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.

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

"Mechanics of Segmentation along Normal Faults": supported by the Texas Higher Education Coordinating Board.

"Mined Lands Inventory, East Texas": supported by the Railroad Commission of Texas.

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

"Plans for Reopening Packery Channel": supported by the General Land Office of Texas.

"Preparation of Supporting Materials and Assistance provided by Robert A. Morton in Open Beaches Litigation": supported by the Attorney General's Office of Texas.

"Salt Tectonics on the Continental Slope, Northern Gulf of Mexico": supported by the Texas Higher Education Coordinating Board.

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

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

"Scale Modeling of Hydrocarbon Traps Formed by Diapirism and Growth Faulting"

"Rollover Kinematics of Growth Faults"

"Hydrogeologic Description of Pressure Chambers and Application to Enhanced Oil and Gas Recovery"

"Kinetic and Geochemical Aspects of Near-Surface Dolomitization."

Private

"Abandoned Well Characterization Study": supported by the American Petroleum Institute.

"Application of Sequence-Stratigraphic Concepts to the Tainan Basin": supported by the Chinese Petroleum Corporation.

"Application of Sequence-Stratigraphic Concepts to the Western Offshore Atlantic Basins": supported by SOEKOR Ltd.

"Applied Geodynamics Laboratory": research continued with new support from Elf-Aquitaine Petroleum, Total Minatome Corporation, Phillips Petroleum Company, Chevron Oil Field Research Company, BP Exploration, ARCO Oil and Gas Company, Petrobras, Mobil Research & Development Corporation, Marathon Oil Company, DuPont (Conoco, Inc.), Agip, S. p. A., and Amoco Production Company.

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

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

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

"Characterization of San Andres and Grayburg Reservoirs": research continued with new support from UNOCAL, Chevron Oil Field Research Company, Marathon Oil Company, Exxon Company, USA, Shell Oil Company, Mobil Exploration & Producing U.S. Inc., Amoco Production Company, ARCO Oil and Gas Company, Agip, S. p. A.

"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.

"Genetic Stratigraphy, Depositional Systems, Structural Evolution, and Petroleum Exploration Potential: NW Gulf of Mexico Continental Shelf": research continued with new support from Standard Oil Production Company.

"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.

"Mapping in the Area Between the Kleberg County Line and the Port Aransas Jetties": supported by Shiner, Moseley and Associates, Inc.

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

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

"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 80-year history, the Bureau has published nearly 2,175 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 1989, about 25,000 volumes were distributed. The Bureau issued the following publications in 1989:

Special Publications

Atlas of Major Texas Gas Reservoirs

by E. C. Kosters, D. G. Bebout, S. J. Seni, C. M. Garrett, Jr., L. F. Brown, Jr., H. S. Hamlin, S. P. Dutton, S. C. Ruppel, R. J. Finley, and Noel Tyler. 161 p., 459 maps, cross sections, and logs, 77 tables, 4 full-color plates, in large format (17 by 22 inches) ($62.36, including tax)

Compilation of information on natural gas in Texas

A companion to the 1983 *Atlas of Major Texas Oil Reservoirs*, this volume contains information on more than 1,828 reservoirs, with emphasis on 868 reservoirs that have cumulative gas production of greater than 30 Bcf of natural gas. Texas gas reservoirs are classified into 73 plays, each of which is described in terms of its principal geologic and engineering production characteristics. This assessment of the similarities of gas occurrence within each play will assist in defining controls on gas accumulation, in identifying resources affected by new technology, and in expanding technology to maximize recovery through improved field development and production practices. The *Atlas of Major Texas Gas Reservoirs* is a jointly funded and jointly issued publication of the Bureau of Economic Geology, The University of Texas at Austin, and the Gas Research Institute.

Submerged Lands of Texas, Kingsville Area: Sediments, Geochemistry, Benthic Macroinvertebrates, and Associated Wetlands

and

Submerged Lands of Texas, Port Lavaca 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, H. S. Nance, and others. ($12.50 each)

Final volumes in the Submerged Lands of Texas series, providing a detailed inventory of submerged lands and associated wetlands in the Kingsville and Port Lavaca areas 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. These two atlases, both issued in 1989, are the final two in a series of seven of submerged lands atlases that provide comprehensive sedimentological, geochemical, and biological data for management of coastal areas. During this 11-year program, 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. In each atlas, 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. Throughout the project, 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.

The Kingsville atlas contains 137 pages, 66 figures, 19 tables, and 6 plates; the Port Lavaca atlas has 165 pages, 60 figures, 16 tables, and 6 plates.

Reports of Investigations

RI 180. Geomorphic Processes and Rates of Retreat Affecting the Caprock Escarpment, Texas Panhandle

by T. C. Gustavson and W. W. Simpkins. 49 p., 30 figs., 6 tables ($3.00)

Description of geomorphic, structural, stratigraphic, and hydrologic conditions in the Caprock Escarpment, Southern High Plains

The Caprock Escarpment, which bounds the eastern margin of the Southern High Plains of the Texas Panhandle, developed and is maintained by surface and subsurface erosional processes. To assess these geomorphic and hydrologic processes and the rates at which they are occurring, the authors reviewed existing research on the Caprock Escarpment and analyzed and interpreted data from outcrops, geophysical logs, core samples, and ground and surface water. They describe surface processes such as slope wash, rill wash, slumping, rock falls, spring sapping, seepage erosion, and piping, the effects of precipitation and runoff, and the subsurface processes of salt dissolution and collapse of overlying strata. Rates of retreat of the Caprock Escarpment and rates of westerly advance of the salt dissolution zone are similar, the authors conclude, amounting to approximately 0.01 to 0.20 km/1,000 yr. This research was funded by the U.S. Department of Energy Salt Repository Project Office.

RI 181. Internal Structure of Mushroom-Shaped Salt Diapirs

by M. P. A. Jackson and C. J. Talbot. 35 p., 24 figs. ($2.50)

Structural analysis of mushroom-shaped diapirs produced by dynamically scaled centrifuge experiments compared with natural examples from the U.S. Gulf Coast, West Germany, Canada, and Iran

This report focuses on the dynamics and kinematics of salt diapirs with crestal bulbs shaped like a mushroom, one of the most complex types of diapirs, as interpreted by experimental modeling and from naturally occurring examples. Direct, practical applications of this research include use in the evaluation of salt domes as repositories for radioactive waste, in the exploration and production of salt, potash, and sulfur, and in the search for subtle hydrocarbon traps. The authors conducted 8 centrifuge experiments, which produced more than 100 model diapirs. These experiments were dynamically scaled to U.S. Gulf Coast salt domes, but the qualitative results are also relevant to salt diapirs in other provinces and to granitoid diapirs penetrating metamorphic crust. The centrifuged domes grew under overburdens of constant thickness or under aggrading and prograding overburdens, a new experimental approach. Results indicate that external mushroom structure results from toroidal circulation of buoyant source and immediate cover having similar effective viscosities, whereas internal structure is produced by toroidal circulation confined within the diapir. The internal diapir structure elucidates the mechanics of emplacement and indicates whether an external mushroom shape can be expected and sought by further exploration. This research was supported by the U.S. Department of Energy Salt Repository Project Office.

RI 182. Lithogenetic Stratigraphy of the Triassic Dockum Formation, Palo Duro Basin, Texas

by D. A. Johns. 71 p., 41 figs., 2 tables, 3 appendices ($4.00)

Description and interpretation of the deposition and lithofacies of the Dockum Formation (Triassic), Texas Panhandle

Using approximately 350 well logs and cores from 4 wells, the author examines the depositional origin of the Dockum, discusses the distribution of lithofacies within the basin, and assesses the influences on trends in sandstone thickness. Outcrops were examined along the Eastern and Western Caprock Escarpments in Texas and eastern New Mexico, and facies interpretations were projected into the subsurface to improve regional analysis of the Dockum. Four new cores of subsurface Dockum were described and interpreted, forming the nucleus of subsurface lithofacies identification. The report focuses on the lower Dockum, within which the author identified four depositional sequences. These sequences, presented on cross sections and net-sandstone and paleogeographic maps, document a progression from continental-dominated depositional systems to lacustrine-dominated systems.

Three types of systems tracts were identified within these sequences: highstand lacustrine and deltaic, lowstand continental, and lowstand valley-fill and retrogradational deltaic systems. Three lithofacies are identified on well logs, and their vertical and lateral distribution and changes in distribution patterns and depositional implications are discussed. Results of this study can be applied to depositional and stratigraphic studies of Triassic rocks in the Palo Duro and Midland Basins and toward evaluation of water resources in the Dockum and the overlying Ogallala and underlying Cretaceous aquifers.

RI 183. Geology and Tertiary Igneous Activity of the Hen Egg Mountain and Christmas Mountains Quadrangles, Big Bend Region, Trans-Pecos Texas

by C. D. Henry, J. G. Price, and D. E. Miser. 105 p., 35 figs., 5 tables, 1 appendix, 2-sheet full-color map and explanation ($12.50)

Stratigraphic, structural, and mineralogical study of Tertiary volcanic and volcaniclastic rocks in the Christmas Mountains area near Big Bend National Park

This report details the volcanic and volcaniclastic stratigraphy and evaluates the potential for ore deposits within the Hen Egg Mountain and Christmas Mountains quadrangles. Detailed (1:24,000-scale) geologic mapping, presented as a full-color map with the report, provides the basic geologic framework for this study of the origin and evolution of the igneous rocks of the area. Magmatism in the two-quadrangle area spans the entire time of magmatism in the Trans-Pecos volcanic province (Eocene to Miocene) and composes the major part of the earliest activity in the province. The intrusions vary widely in size, form, composition, and origin; both silica-undersaturated and silica-oversaturated rocks are well represented. Silicic volcanism accompanied late Eocene intrusion and is best exemplified in the Christmas Mountains by a caldera complex associated with an unusual eruptive laccolith, a caldera type not previously recognized. The complex produced an extensive series of rhyolitic to quartz trachytic tuffs, silicic lavas and domes, and debris-avalanche deposits, all of which are divided into five stratigraphic sequences. Survey of the economic minerals and numerous prospects associated with intrusive rocks within the study area indicates that the potential is moderate to high for the discovery of fluorspar, beryllium, mercury, molybdenum, silver, and some specialty metals. Funding was provided by the U.S. Geological Survey and by the Texas Mining and Mineral Resources Research Institute.

RI 184. Geologic Occurrence and Regional Assessment of Evaporite-Hosted Native Sulfur, Trans-Pecos Texas

by T. F. Hentz, J. G. Price, and G. N. Gutierrez. 70 p., 51 figs., 7 tables, 1 plate ($6.00)

Analysis of sulfur occurrence and production in West Texas

In Trans-Pecos Texas, native sulfur is concentrated in two areas, the Rustler Springs and Fort Stockton districts. Sulfur was first observed in the Rustler Springs area in 1854 and first mined in the early 1900's. Today, Pennzoil's Culberson mine, having a cumulative (1969–1985) production of more than 28 million long tons of sulfur, is the largest producing mine in the Western Hemisphere. After oil and gas, sulfur is the second most economically valuable mineral commodity in the state; revenues generated from royalties, permits; and lease and land sales significantly affect the State's economy. Funded jointly by the General Land Office of Texas (GLO) and the U.S. Bureau of Mines, this study examines the structure, stratigraphy, and sulfur potential of the Rustler Springs and Fort Stockton areas. Data were gathered from GLO prospect permit files, including data from 1,450 exploratory sulfur wells in Culberson, Reeves, and Pecos Counties. Borehole data were used in constructing contour maps of depth to sulfur and net and gross thickness of sulfur. Two IBM-compatible diskettes containing borehole (formation tops, sulfur-bearing zones) and tract-assessment data from the Rustler Springs and Fort Stockton sulfur districts are available separately ($3.70).

RI 185. Fracture Analysis of the Travis Peak Formation, Western Flank of the Sabine Arch, East Texas

by S. E. Laubach. 55 p., 41 figs., 6 tables ($4.00)

Study of types of fractures in the Travis Peak and their significance to oil and gas production

Funded by the Gas Research Institute, this project is part of an extensive regional coring program in the Lower Cretaceous Travis Peak Formation in the East Texas Basin designed to improve gas production from low-permeability gas sandstones. Fracture analysis is important both because fractures are hydrocarbon reservoirs and conduits to other reservoirs and because they affect the success of production techniques such as hydraulic fracture treatment. In this study the author used descriptions of 565 fractures from more than 2,100 ft of 4-inch-diameter core from 8 Travis Peak wells. Petrographic studies focused on Waskom field in Harrison County, eastern and western Panola County, and northern Nacogdoches County. Both borehole televiewer and formation microscanner logs were used, as were analyses made using a scanning electron microscope and a petrographic microscope. Natural fractures were most prevalent in Travis Peak areas that have highly cemented sandstone; unless compensated for, natural fractures could adversely affect hydraulic fractures by creating multiple, curved fracture strands and by promoting leakoff of fracturing fluid. Thus, natural fractures need to be considered in hydraulic fracture treatment design and in evaluations of hydraulic treatment results and postfracture production and pressure buildup data.

RI 186. Karst-Controlled Reservoir Heterogeneity and an Example from the Ellenburger Group (Lower Ordovician) of West Texas

by Charles Kerans. 40 p., 25 figs. ($2.50)

Subsurface study of the Ellenburger Group

Reservoir characterization of the Ellenburger Group carbonate-platform facies was conducted as part of a larger, ongoing study funded by The University of Texas System of oil-bearing strata of the Permian Basin beneath University Lands. The Ellenburger had produced more than 1.4 billion barrels of oil through 1985, making it one of the major reservoir intervals in the Permian Basin. However, complex lithologic heterogeneity of the reservoirs allows only moderate recovery efficiency. Compartmentalization in the Ellenburger was produced by prolonged subaerial exposure and karstification of the carbonate platform during a eustatic lowstand prior to transgression of the overlying Simpson Group. In the study area (Central Basin Platform and Midland Basin), karst modification occurs as the pervasive development of carbonate breccias, which compose cave-roof and cave-floor facies. An intervening cave-fill facies, consisting of resedimented, clay-rich clastics of the Simpson Group, acts as an effective vertical flow barrier between the oil-bearing karst breccias. Lateral reservoir heterogeneities formed by localized collapse structures in the Ellenburger cave system. Field-scale analyses indicate that secondary and tertiary recovery programs can be improved by the integration of these karst-model concepts.

RI 187. Tectonic Structures of the Palo Duro Basin, Texas Panhandle

by R. T. Budnik. 43 p., 31 figs., 1 table ($3.00)

Description of tectonic features in and adjacent to the Palo Duro Basin

As part of an extensive basin analysis program conducted by the Bureau for the U.S. Department of Energy, this research summarizes the structural geology of the Palo Duro Basin. Surface and subsurface study, including examinations of outcrop, well log, and seismic reflection data, indicate that the structures within and adjoining the Palo Duro Basin consist primarily of isolated, fault-bounded, basement highs and poorly defined subbasins. Overall structural configuration of these features was produced during the Pennsylvanian Ancestral Rocky Mountain Orogeny and modified by subsidence during the Permian and Triassic Periods, although some structures formed before the late Paleozoic and were later reactivated. Recognized structures in the Palo Duro Basin include the Arney positive in Castro, Randall, and Swisher Counties, the central Randall High in Randall County, and the Littlefield-Illusion Lake structure in Lamb County. Structures marginal to the Palo Duro Basin include the Amarillo Uplift, Whittenburg Trough, Oldham-Harmon trend, and the Matador Arch; in this report the author delineates these and other structures in detail.

RI 188. Organic Petrography and Organic Geochemistry of Texas Tertiary Coals in Relation to Depositional Environment and Hydrocarbon Generation

by P. K. Mukhopadhyay. 118 p., 36 figs., 14 tables, 5 appendices ($9.00)

Petrographic and geochemical analyses of Texas lignites

Comprehensive organic petrological, organic geochemical, and chemical analyses were conducted on 156 samples of Tertiary coals from the Wilcox, Claiborne, and Jackson Groups in northeast, east-central, East, and South Texas. Samples were collected from outcrop, near-surface mines, and boreholes and classified into three maceral types (humic, mixed, and sapropelic) on the basis of hydrocarbon potential and maceral composition. Maceral types are abundantly illustrated in the report by both black-and-white and color photomicrographs. The author used ternary diagrams of maceral-composition relations between ratios of macerals of similar affinity, selected palynological data, and physicochemical properties to distinguish specific peat-forming paleoenvironments within the Tertiary strata. These data establish the variability of depositional environments, depositional relations between maceral groups, and chemical properties of the Texas coals. Procedures used to evaluate hydrocarbon chemistry include Rock-Eval pyrolysis, gas chromatography, and hydrous and anhydrous pyrolysis. This study was partially funded by the U.S. Geological Survey.

RI 189. Stochastic Analysis of Aquifer Interconnectedness: Wilcox Group, Trawick Area, East Texas

by G. E. Fogg. 68 p., 41 figs., 4 tables, 5 appendices ($5.50)

Statistic assessment of aquifer interconnectedness

In this report, conditional simulation, a geostatistical technique that transforms geologic data and interpretation into a quantitative form, is introduced as a method for estimating aquifer interconnectedness. Ground-water flow and advective mass transport in the subsurface are controlled primarily by the distribution of hydraulic conductivity (K). However, the inability to characterize K distribution sufficiently by direct measurement is a major obstacle to constructing reliable predictive models of fluid transport. One alternative is to use geological information and geostatistics to characterize interconnectedness of critical K facies that have a dominant influence on fluid flow. The author uses a test case in a 6-by-11-mile region in the East Texas Wilcox Group, a fluvial multiple-aquifer system, to demonstrate the feasibility of this approach. In the test area, conditional simulation provided a workable method of estimating two-dimensional sand-body interconnectedness and between-well heterogeneity in the clastic aquifers.

Geological Circulars

GC 89-1. Shoreline and Vegetation-Line Movement, Texas Gulf Coast, 1974 to 1982

by J. G. Paine and R. A. Morton. 50 p., 15 figs., 5 tables, 3 appendices ($3.00)

Synopsis of recent shoreline and vegetation-line changes and their causes

The Texas Gulf shoreline, which extends more than 350 miles from the Rio Grande to Sabine Pass, comprises barrier islands, peninsulas, and deltaic lobes. Historical shoreline and vegetation-line movement (from the middle 1800's to 1974) along these landforms was documented in a series of Bureau circulars published from 1974 to 1977. This report updates shoreline and vegetation-line changes through 1982. The authors analyze aerial photographs, compare the recent changes with those in the past, and examine the influence of environmental variables such as storms, sea level, subsidence, and sediment supply on the movement of coastal boundaries. The authors conclude that Texas shorelines and vegetation lines retreated between 1974 and 1982, thus continuing

a long-established trend. Retreat was relatively slow during this period, which was a time of few tropical cyclones, comparative sea-level stability, average river discharge, and average rainfall. Approximately 330 acres of Gulf beach was eroded, and vegetation was removed from about 2,000 acres of beach. Erosion was most rapid at the Brazos–Colorado and Rio Grande fluvial-deltaic headlands. Hurricane Allen, which made landfall on South Padre Island in 1980, had relatively little effect on Texas shorelines but caused nearly coastwide retreat of the vegetation line, which by 1982 had not recovered from the effects of the hurricane.

GC 89-2. Hydrocarbon Production and Exploration Potential of the Distal Frio Formation, Texas Gulf Coast and Offshore

by H. S. Hamlin. 47 p., 42 figs., 4 tables, 2 plates ($3.50)

Assessment of Frio Formation oil and gas

The Frio Formation composes one of the principal progradational clastic wedges and hydrocarbon reservoirs of the Texas Gulf Coast Basin. However, the distal portion of the Frio, a deep hydrocarbon province, is underexplored relative to the onshore Frio. The regional depositional and structural framework of the distal Frio was described in Bureau of Economic Geology GC 86-8 by W. E. Galloway. In Bureau GC 89-2, the author divides the distal Frio into geologically defined plays and then tabulates, maps, and analyzes Frio discovery and production data for each play. Coastwide mapping of distal Frio porosities, temperatures, and pressures provides a basis for ranking reservoir quality in each play. The author describes typical fields from each of the major plays as examples of potential new-field discoveries offshore. Integration of geological framework, production trends, and reservoir properties allows the author to outline and rank optimal fairways for distal Frio exploration offshore. Most favorable exploration potential lies in the Galveston and Mustang Island offshore areas.

GC 89-3. A Compendium of Earthquake Activity in Texas

by S. D. Davis, W. D. Pennington, and S. M. Carlson. 26 p., 4 figs., 3 tables, 3 appendices on 4 microfiche ($3.50)

Compilation of data of all earthquakes reported on in Texas

This circular provides a complete listing and evaluation of Texas earthquake activity from the period 1847 to 1986. The authors draw from a variety of information sources, including published accounts (government earthquake compendia, scientific journal articles, and newspaper articles), weather bulletins, and personal letters and diaries. The document contains both a discussion section in which the geology and geophysics of separate seismically active regions in Texas are analyzed (West Texas, Texas Panhandle, Ouachita Belt, Gulf Coastal Plain) and comprehensive appendices (microfiche) that summarize all available data regarding separate earthquake events. Such appendix data include (1) best estimates of epicentral locations, (2) magnitudes, (3) felt areas, (4) intensities, and (5) data sources. The authors also examine discrepancies among data sources and, where necessary, present new interpretations of earthquake data on the basis of the compiled information.

GC 89-4. Oil and Gas Resources Remaining in the Permian Basin: Targets for Additional Hydrocarbon Recovery

by Noel Tyler and N. J. Banta. 20 p., 14 figs., 3 tables ($2.00)

Resource assessment of the Permian Basin

In this report the authors present a reevaluation of the oil and gas resource base remaining in existing Permian Basin reservoirs. The Permian Basin is one of the nation's premier sources of oil production, accounting for almost one quarter of the total domestic oil resource. The distribution and magnitude of oil and gas resources discovered in the basin are documented at the play and reservoir levels. Data on reservoir geology and volumetric analysis come from the oil and gas atlases published by the Bureau of Economic Geology, the Bureau's oil-reservoir data base, and NRG Associates' "Significant Oil and Gas Fields of the United States."

Projected ultimate recovery from Permian Basin reservoirs is low, averaging only 30 percent of the original oil in place. Thus, of the 106 billion barrels of oil discovered in the basin, 75 billion barrels remain. This resource consists of mobile and residual oil. The geographic and stratigraphic distribution of these resources is discussed in relation to the depositional setting of the host reservoirs. The authors conclude that 88 percent of the unrecovered oil lies at shallow depths of less than 8,000 ft.

Cross Sections

Structural Cross Sections, Plio-Pleistocene Series, Southeastern Texas Continental Shelf

by R. A. Morton and L. A. Jirik. 7-p. text, 13 plates ($6.00)

Series of cross sections illustrating the regional structure and stratigraphy beneath the Texas continental shelf

The Plio-Pleistocene Series in the western Gulf Coast basin comprises a thick wedge of terrigenous clastic sediment that produces modest volumes of hydrocarbons from offshore leases along the outer shelf and upper slope. Sandstone reservoirs within this wedge have yielded more than 40 million bbl of oil and 2.5 Tcf of gas. They initially contained about 1.6 billion bbl of oil equivalent, or nearly two-thirds of the estimated total recoverable reserves beneath the Texas Outer Continental Shelf. To interpret the structural and stratigraphic framework of the area, the authors used publicly available electric logs, paleontological reports, and published information, in addition to proprietary data released by operators and approximately 2,000 miles of multichannel seismic profiles. Biostratigraphic zones of the Plio-Pleistocene Series, locations of major oil and gas fields and trends, and areas of tectonic features and salt structures are included. This study is part of an industry-supported research project supported by CNG Producing Company, The Louisiana Land and Exploration Company, Mobil Exploration and Producing US, Inc., Pennzoil Exploration and Production Company, Standard Oil Production Company, Tenneco Oil Exploration and Production, Texaco USA, and Total Minatome.

Mineral Resource Circular

MRC 81. The Mineral Industry of Texas in 1987

by J. P. Ohl and M. W. McBride. 12 p., 1 fig., 7 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 1987* 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.

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 regarding holdings, policies, and computer listings may be obtained by calling Allan R. Standen, Curator, at (512) 471-1534, ext. 401. A brochure describing the CRC is available on request.

Approximately 6,250 cores and 53,500 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 1989, the CRC received more than 415 patrons. Transactions involving CRC inventory included material from 781 wells and required the transfer of more than 17,530 boxes of core to and from viewing and shipping areas. Core processing, including the slabbing and reboxing of wells, totaled 35,173 linear feet. The thin section laboratory produced more than 1,605 thin sections for both Bureau and non-Bureau patrons.

New acquisitions of core and cuttings in 1989 total more than 101,043 linear feet and include material from counties in Texas, California, Florida, New Mexico, Oklahoma, and Wyoming, parishes in Louisiana, and core from the Bahamas. Materials were donated by Amerada Hess, Thomas D. Coffman Exploration, Core Labs, Desert Resources Inc., Everest Minerals, Freeport Sulfur, Hagen-Greenbriar Exploration, Hubert Harrison, International Technology Corporation, Mobil Oil, Palo Duro River Authority, PanCanadian Petroleum, Petroleos Mexicanos, Reservoirs Inc., Danny Spaeth Mining, Texas National Research Laboratory Commission, Texas A&I, Texas Low-Level Radioactive Waste Disposal Authority, Terratek, Union Oil of California, the U.S. Geological Survey, and Western Atlas International.

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 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 analyses and characterization efforts during 1989. Among these are the Low-Level Radioactive Waste Isolation program, Texas Mining and Mineral Resources Research Institute, State Submerged Lands, Well Head Protection Areas, University Lands, Texas Advanced Research Program, Reservoir Characterization Research Laboratory, and Big Bend Ranch State Natural Area projects. In addition to supporting Bureau projects, MSL staff provided analytical services for the Institute of Gas Technology's Pleasant Bayou and Hulin test wells, UT Center for Energy Studies (DOE Logging), and the Texas Department of Parks and Wildlife.

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 1989, approximately 2,000 such requests were handled by Mary McBride and L. Edwin Garner, the new Public Information Geologist.

Reading Room/Data Center

The Bureau's Reading Room/Data Center provides a wide range of geological data and information to staff members, students, and visitors interested in Texas geology. The facility, supervised by 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 1989, Reading Room staff cataloged, indexed, entered into a computer data base, and shelved more than 1,000 items. 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 are archived at the University's Barker History Center.

Geophysical Log Facility

The Geophysical Log Facility (GLF), managed by L. Edwin Garner, is housed in the Bureau's Reading Room/Data Center. The facility was established by State legislation, effective September 1, 1985, that requires 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 1989, the facility had accumulated approximately 50,000 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

Bureau Named Manager of SLERO Center

In September 1989 the Office of the Governor awarded research funds to a consortium of State universities to establish a State Lands Energy Resource Optimization (SLERO) Center, of which the Bureau has been assigned overall managerial control. This research program involves the development of improved petroleum-recovery strategies to enhance production from reservoirs on State Lands using advanced geologic, engineering, and geophysical approaches. Members of the consortium are The University of Texas at Austin, the University of Houston, Texas A&M University, and Texas Tech University. Work will also be performed by other University of Texas at Austin departments, such as the Center for Petroleum and Geosystems Engineering, the Department of Chemistry, and the Department of Geological Sciences. The Houston Area Research Center and the General Land Office will also be involved in the program. Projects will emphasize the near-term potential of enlarging Public School and Permanent University Fund revenues. A more detailed discussion of the SLERO project is presented in the "Energy Resources Investigations" section of this annual report.

Bureau Co-Hosts Second Continental Margins Symposium

The Bureau, the Minerals Management Service (MMS) of the U.S. Department of the Interior, and the Continental Margins Committee of the Association of American State Geologists sponsored the second symposium on "Studies Related to Continental Margins" this spring at the Balcones Research Center. The symposium drew 48 geoscientists from 21 states, including representatives from the MMS and the U.S. Geological Survey. Participants reviewed research results from the third and fourth years of fuel and non-fuel mineral studies supported by MMS. Papers presented by representatives of states under contract with MMS summarized the varied research on the geologic framework, petroleum resources, and strategic minerals associated with continental margins. Presentations were also given by representatives of the regional and headquarters offices of MMS.

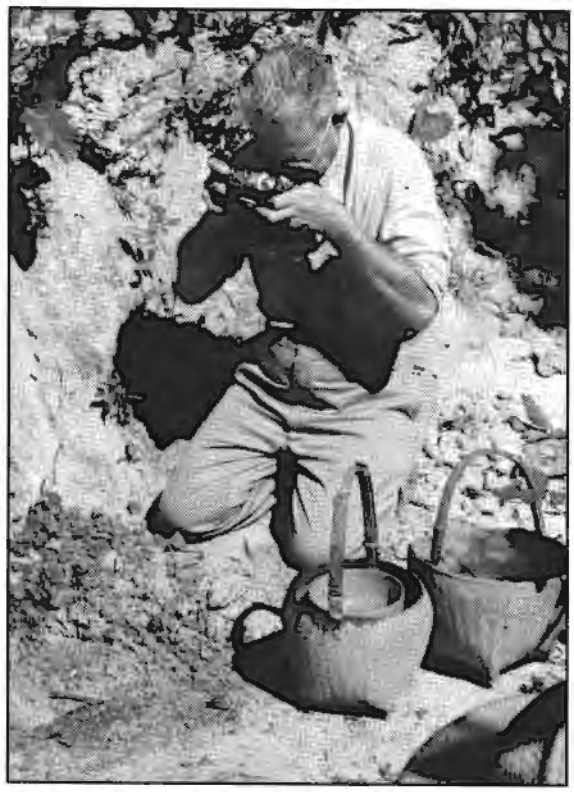
Fisher Chairs Governor's Task Force

At the request of Texas Governor William P. Clements, Jr., Bureau Director William L. Fisher headed a task force of researchers from The University of Texas at Austin to examine procedures and methods to stabilize U.S. oil prices, a major influence on the country's economy as a whole. Other members of the task force included Martin L. Baughman, electrical and computer engineering and Center for Energy Studies; Stephen L. McDonald, economics; James W. McKie, economics; Peter K. Nance, energy and mineral resources; Walt W. Rostow, economics; Ernest E. Smith, law; and Sten A. Thore, economics. The task force proposed specific recommendations that are outlined in a report presented in 1989 to the Governor.

"Youth Opportunities Unlimited" Students at Bureau for the Summer

Seven Texas high school students worked at the Bureau this summer through the Youth Opportunities Unlimited (YOU) program. YOU, sponsored by the Private Industry Councils through the Job Training Partnership Act, provided students with summer jobs and a way to learn about various careers. This program also offered the Bureau an opportunity to work with enthusiastic young people, to teach them more about our professions, and to help instill good work habits in those who will be entering the work force in a few years. The students, who lived on the University campus, worked four hours per day and also took English and mathematics classes for high-school credit, a physical education class of their choice, and career-awareness classes in the afternoon and evenings. Field trips were scheduled during the students' off hours.

Awards and Honors



Virgil E. Barnes photographing an excavated Muong Nong-type tektite occurrence near Nong Sapong, Thailand.

Virgil E. Barnes received the 1989 Barringer Award at the Annual Meeting of the Meteoritical Society held this year in Vienna, Austria. The award, named in honor of Daniel Moreau Barringer (1860–1929) in recognition of his pioneering work in the field of meteoritics, is presented annually to a member of the Society who has contributed outstanding work in the field of impact cratering or in closely related phenomena. Barnes has been so honored for his innovative and extensive research into the origins of tektites, glass objects found in five strewn fields around the world, one of which includes Texas. Upon acceptance of the award, Barnes remarked:

> ...I feel empathy with Daniel Moreau Barringer, whose recognition of the Coon Butte as a meteorite crater was so long denied by geologists and astronomers. I, too, was frustrated when many scientists continued to believe that tektites were of meteoritic origin even after I had shown in my 1940 publication on North American Tektites that tektites are fused earth materials...
>
> ...With the start of the space program, interest in tektites revived in the belief that they may be samples of moon materials. I felt so strongly about scientists ignoring the evidence...showing that tektites could not possibly be from the moon...that I applied for and received National Science Foundation support to make a world-wide study of tektite strewn fields to determine if physical evidence could be found in the field to show clearly that tektites are of earthly origin. The layered tektites of southeast Asia...provided the critical evidence...that tektites are the result of impacts on Earth by extraterrestrial bodies, the most likely of which appear to be comets...

Barnes, who has been a member of the Bureau staff since 1935, specializes in the geology of Texas, particularly the Llano region of Central Texas. 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 depicting the entire state. Barnes is also a Professor Emeritus of the Department of Geological Sciences, The University of Texas at Austin, and Associate Curator of meteorites and tektites at the Texas Memorial Museum in Austin.

L. F. Brown, Jr., Stephen E. Laubach, Richard P. Major, Robert W. Baumgardner, Jr., and **Mark H. Holtz** were recognized for outstanding oral presentations at annual professional society meetings this year. Brown presented a paper entitled "Reexploration of Cratonic Basins Using Passive-Margin Sequence-Stratigraphic Concepts: Examples from Upper Paleozoic Rocks, Eastern Margin, Midland Basin" to the American Association of Petroleum Geologists (AAPG) in San Antonio. He and six others were invited to present their papers again in the "Best of AAPG" session at the 1989 annual meeting of the Society of Exploration Geophysicists held in Dallas. Major and Holtz were honored by the Society of Petroleum Engineers (SPE) for their paper "Effects of Geologic Heterogeneity on Waterflood Efficiency at Jordan Field, University Lands, Ector and Crane Counties, Texas" as "Best of AAPG for SPE." They presented their paper at the SPE Annual Technical Conference and Exhibition. The paper by Laubach and Baumgardner entitled "Fracture Detection in Low-Permeability Reservoir Sandstone: A Comparison of BHTV and FMS Logs to Core" won honors as "Best of SPE for AAPG" at the SPE annual conference and by invitation was presented again at the 1989 AAPG annual meeting.

Charles W. Kreitler received the annual Seagram Foundation Fellowship to visit and present lectures at the major ground-water research groups in Israel during the fall of 1989. The recipients of this award, chosen by a board of Israeli academics, are non-Israeli agricultural or water scientists of international stature. Kreitler visited the Israel Geological Survey, Technion Institute, the Weizmann Institute and Faculty of Agriculture of the Hebrew University, the Blaustein Institute for Desert Research, and the Israel Hydrologic Service. He presented lectures concerning the hydrogeology of sedimentary basins, ground-water exploration in arid settings, and water chemistry as a tracer of ground-water flow systems.

The 1989 Transactions of the Gulf Coast Association of Geological Societies was dedicated to **William L. Fisher** "in recognition of his many outstanding contributions to the geological profession through research, administration, teaching, professional affairs, and distinguished public service." Fisher was also elected this year as Vice President and President-Elect of the American Geological Institute and as Councilor of the Geological Society of America.

Martin P. A. Jackson and **Charles W. Kreitler** were elected Fellows of the Geological Society of America this year in recognition of their research in salt tectonics and hydrogeology, respectively, and their service to the Society.

New Research Staff

Jeffrey D. Grigsby joined the Bureau in July as a post-doctoral Research Fellow to work on the Secondary Gas Recovery project. His initial responsibilities involve analysis of the diagenesis of Tertiary Gulf Coast sands. Grigsby received a Ph.D. in geology from The University of Cincinnati. His dissertation concerned the petrographic and chemical analyses of detrital Fe-Ti oxides in modern sands and their relationship to provenance.

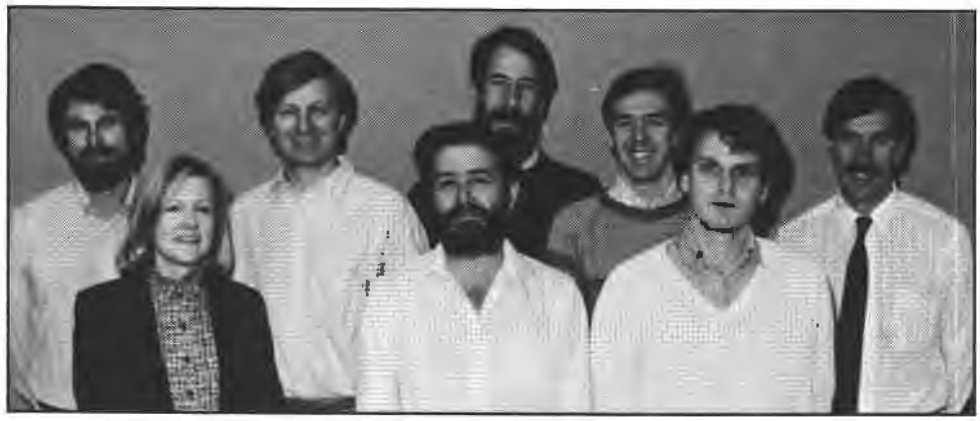
Douglas S. Hamilton, a post-doctoral Research Fellow and native of Australia, joined the Bureau in December to work on the SLERO project by characterizing Gulf Coast terrigenous clastic reservoirs. Hamilton completed his Ph.D. in geology at the University of Sydney, where he studied the sedimentology of the Permo-Triassic Gunnedah Basin of Australia and its application to oil and coal exploration.

Eric W. James, a post-doctoral Research Fellow at the Bureau, joined the staff in August to work on various projects in Trans-Pecos Texas for the Texas Mining and Mineral Resources Research Institute. His studies involve analysis of the geochemistry and isotopic characteristics of igneous rocks and associated ore deposits. James earned his Ph.D. in geology from the University of California, Santa Barbara. He recently completed a post-doctoral fellowship at the California Institute of Technology, where he worked on the Cajon Pass Drilling Project, the nation's first project involving scientific deep drilling in the continental crust.

Richard P. Langford joined the Bureau in January as a Research Associate to work on the Secondary Gas Recovery project. His initial duties involve using facies models to identify untapped and bypassed natural gas reservoir compartments in the Oligocene Vicksburg and Frio Formations of the Texas Gulf Coast. Langford completed his Ph.D. in geology at the University of Utah, where he studied the interactions between fluvial and eolian depositional environments in both modern settings and in the Permian Cutler Formation and Cedar Mesa Sandstone of the Colorado Plateau.

J. Ulises Ricoy, a native of Mexico, joined the Bureau in November as a post-doctoral Research Fellow to work on the SLERO project. His initial duties involve geologic characterization of a variety of reservoirs on State Lands. Ricoy completed his Ph.D. degree in geology at The University of Texas at Austin. His dissertation concerned seismic- and sequence-stratigraphic analysis of terrigenous clastic depositional systems of the Mexican Isthmus basins.

Daniel D. Schultz-Ela joined the Bureau's Applied Geodynamics Laboratory in February as a Research Associate to develop numerical models and tools for quantitative analysis of the physical tectonic models produced by the lab. Schultz-Ela studied strain patterns and their tectonic implications in an Archean greenstone belt for his Ph.D. in geology from the University of Minnesota. Before coming to Austin he returned to



New Bureau Research staff members, left to right: (back row) Richard P. Langford, Eric W. James, Daniel D. Schultz-Ela, Jeffrey D. Grigsby, Douglas S. Hamilton (front row) Sally G. Zinke, J. Ulises Ricoy, Bruno C. Vendeville

his home state to teach for 2 years at Colorado College in Colorado Springs.

Bruno C. Vendeville, a native of France, joined the Bureau in January as a post-doctoral Research Fellow, also to work in the Bureau's Applied Geodynamics Laboratory. His initial work involves the design and construction of the 1g modeling laboratory and experimentation on the interaction of subsurface salt flow, diapirism, and faulting. Vendeville earned his Ph.D. in geology at the University of Rennes, France, where he studied physical modeling of faulting during extensional processes that included basement-controlled faulting, gravitational sliding, and growth faulting. Before coming to the Bureau, Vendeville was a post-doctoral Associate at the Center for Tectonophysics at Texas A&M University.

Sally G. Zinke, Research Associate, joined the Bureau in June as a geophysicist to work on the Secondary Gas Recovery project. Her principal duties involve the application of geophysical technology to define reservoir heterogeneities. Zinke received an M.S. degree in geophysics from Pennsylvania State University and an M.B.A. from the University of Denver. Prior to coming to the Bureau, she gained 15 years of diverse petroleum industry experience working for Mobil Oil Corporation and PanCanadian Petroleum Company.

Bureau Veterans Retire

L. F. Brown, Jr., and **Bettye Blitch** retired from the Bureau this year after more than 28 and 14 years of service, respectively.

Frank Brown began working at the Bureau in 1957 and worked for 3 years before joining the teaching staff at Baylor University. He returned in 1966 and rose to the level of Senior Research Scientist, his position upon retirement. Brown has also been a Professor in the Department of Geological Sciences at The University of Texas at Austin since 1971 and was Associate Director of the Bureau from 1971 to 1984, Director of the Texas Mining and Mineral Resources Research Institute from 1982 to 1984, and a Research Scientist from 1957 to 1960 and 1966 to 1971. Brown's primary research interests during his years at the Bureau were the regional depositional environments, litho-stratigraphy, and sequence stratigraphy of the exposed and subsurface upper Paleozoic succession of the Eastern Shelf of the Midland Basin in North-Central Texas. Influenced by early observations of these rocks, he and William L. Fisher and Joseph H. McGowen developed the widely adopted concept of "depositional systems" in the late 1960's. His later research concentrated mostly on the fast-evolving, seismic- and sequence-stratigraphic analysis of depositional basins. Brown is now working full-time as an international geological consultant.

David M. Stephens

Bettye Blitch joined the Bureau in 1975. Since that time she coordinated or was personally responsible for the administration of the numerous payroll, purchasing, accounting, travel, personnel, publication sales, and secretarial functions essential for the day-to-day operation of the Bureau. After starting as an Administrative Secretary, she was promoted to Administrative Assistant in 1978 and to Executive Assistant in 1982.

Research Staff Publications and Activities

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

Papers

Ambrose, W. A., and **Jackson, M. L. W.,** 1989, Geologically based infill potential of fluvial gas reservoirs, La Gloria (Frio) field, South Texas: South Texas Geological Society Bulletin, v. 29, no. 5, p. 13–21.

Ayers, W. B., Jr., 1989, Definition of the coalbed methane reservoir: Gas Research Institute Coalbed Methane Workshop, Technical Session I, Part III, 32 p. *And in* 1989 SPE Gas Technology Symposium, Part A, p. 1–32.

Ayers, W. B., Jr., 1989, Depositional setting of the San Miguel lignite mine, Jackson Group (Eocene), South Texas, *in* Ayers, W. B., Jr., Breyer, J. A., and Finkelman, R. B., eds., Depositional settings of Texas lignites: American Geophysical Union, 28th International Geological Congress, Field Trip Guidebook T173, p. 33–37.

Ayers, W. B., Jr., 1989, Geological settings of lignite in the Wilcox Group of east-central Texas and the Jackson Group of South Texas, *in* Ayers, W. B., Jr., Breyer, J. A., and Finkelman, R. B., eds., Depositional settings of Texas lignites: American Geophysical Union, 28th International Geological Congress, Field Trip Guidebook T173, p. 5–16.

Ayers, W. B., Jr., 1989, Geology of Elgin-Butler clay pits, *in* Ayers, W. B., Jr., Breyer, J. A., and Finkelman, R. B., eds., Depositional settings of Texas lignites: American Geophysical Union, 28th International Geological Congress, Field Trip Guidebook T173, p. 31–32.

Ayers, W. B., Jr., 1989, Geology of Sandow lignite mine, lower Calvert Bluff Formation, east-central Texas, *in* Ayers, W. B., Jr., Breyer, J. A., and Finkelman, R. B., eds., Depositional settings of Texas lignites: American Geophysical Union, 28th International Geological Congress, Field Trip Guidebook T173, p. 26–30.

Ayers, W. B., Jr., Breyer, J. A., and Finkelman, R. B., eds., 1989, Depositional settings of Texas lignites: American Geophysical Union, 28th International Geological Congress, Field Trip Guidebook T173, 37 p.

Ayers, W. B., Jr., Epsman, M. L., and Mink, R. M., 1989, Geologic evaluation of critical production parameters for coalbed methane resources: Gas Research Institute Quarterly Review of Methane from Coal Seams Technology, v. 6, no. 3 & 4, p. 52–58.

Ayers, W. B., Jr., and Kelso, B. S., 1989, Knowledge of methane potential for coalbed resources grows, but needs more study: Oil and Gas Journal, v. 87, no. 43, p. 64–67.

Ayers, W. B., Jr., and Mink, R. M., 1989, Geologic evaluation of critical production parameters for coalbed methane resources: Quarterly Review of Methane from Coal Seams Technology, v. 7, no. 1 & 2, p. 34–37.

Ayers, W. B., Jr., and Zellers, S. D., 1989, Geologic controls on occurrence and producibility of coalbed methane, Fruitland Formation, north-central San Juan Basin, New Mexico: University of Alabama, Proceedings of the 1989 Coalbed Methane Symposium, Paper No. 8925, p. 75–86.

Barnes, V. E., 1989, Origin of tektites: Texas Journal of Science, v. 41, no. 1, p. 5–33.

Bedinger, M. S., Sargent, K. A., and **Henry, C. D.,** 1989, Introduction, *in* Bedinger, M. S., Sargent, K. A., and Langer, W. H., Studies of geology and hydrology in the Basin and Range province, southwestern United States, for isolation of high-level radioactive waste—characterization of the Trans-Pecos region, Texas: U.S. Geological Survey Professional Paper 1370-B, p. B1–B3.

Boerner, S. T., and **Sclater, J. G.,** 1989, Approximate solutions for the heat loss in small marginal basins, *in* Wright, J. A., and Louden, K. E., eds., Handbook of seafloor heat flow: Boca Raton, Florida, CRC Press, p. 231–255.

Brown, L. F., Jr., 1989, A sequence-stratigraphic and systems-tract model for the Virgilian and Wolfcampian Series Eastern Shelf and adjacent Midland Basin, Texas, *in* Boardman, D. R., II, Barrick, J. E., Cocke, Jim, and Nestell, M. K., eds., Middle and Late Pennsylvanian chronostratigraphic boundaries in North-Central Texas: glacial-eustatic events, biostratigraphy, and paleoecology, Part II: Texas Tech University Studies in Geology 2, p. 35–62.

Calnan, T. R., and Littleton, T. G., 1989, Correlation of live mollusks with sediment and bathymetry on the Texas inner shelf: The Veliger, v. 32, no. 2, p. 130–146.

Capuano, R. M., and **Kreitler, C. W.,** 1989, Chemical controls on subsurface degradation of wastes disposed of by deep well injection: Underground Injection Practice Research Foundation, Proceedings of International Symposium on Class I & II Injection Well Technology, p. 345–355.

Cech, Irina, and **Kreitler, C. W.,** 1989, *Reply to* discussion by Philip T. King and John A. Conner of "Radon Distribution in Domestic Water of Texas": Ground Water, v. 27, no. 3, p. 404–407.

Claudy, Nick, Kauffman, M. E., **Milling, M. E.,** and others, 1989, Geoscientific employment and hiring survey: Alexandria, Virginia, American Geological Institute, 84 p.

Duncan, K. M., and **Orr, E. D.,** 1989, Evolution of a network system in a geologic research organization: Society of Petroleum Engineers, Proceedings, 1989 Petroleum Computer Conference, Paper 19143, p. 189–193.

Dutton, A. R., 1989, Hydrogeochemical processes involved in salt-dissolution zones, Texas Panhandle, U.S.A.: Hydrological Processes, v. 3, p. 75–89.

Dutton, A. R., Richter, B. C., and **Kreitler, C. W.,** 1989, Brine discharge and salinization, Concho River watershed, West Texas: Ground Water, v. 27, no. 3, p. 375–383.

Dutton, A. R., and Simpkins, W. W., 1989, Isotopic evidence for paleohydrologic evolution of ground-water flow paths, southern Great Plains, United States: Geology, v. 17, p. 653–656.

Finley, R. J., Brown, L. F., Jr., and **Dutton, S. P.,** 1989, Secondary natural gas recovery: targeted technology

applications for infield reserve growth, *in* Komar, C. A., Malone, R. D., and Byrer, C. W., eds., Proceedings of the natural gas R&D contractors review meeting, prepared for the U.S. Department of Energy, Office of Fossil Energy, under contract no. DOE/METC-89/6103 (DE89011683), p. 6–16.

Fisher, R. S., Posey, H. H., and Kyle, J. R., 1989, Successive pore fluid generations in a Lower Permian brine aquifer, Palo Duro Basin, Texas Panhandle, U.S.A.: Applied Geochemistry, v. 4, p. 455–464.

Fisher, W. L., 1989, Assessing the natural gas resource base: American Gas Association Gas Energy Review, v. 17, no. 6, p. 2–6.

Fisher, W. L. (chairman, American Association of Petroleum Geologists DPA Committee on the Resource Base) and others, 1989, Data support need for exploration—position paper on U.S. oil resources: American Association of Petroleum Geologists Explorer, v. 10, no. 4, p. 42–43.

Fisher, W. L., 1989, Gas resource base is abundant, stable: American Oil and Gas Reporter, v. 32, no. 6, p. 31–37.

Fisher, W. L. (chairman, American Association of Petroleum Geologists DPA Committee on the Resource Base) and others, 1989, Huge gas potential remains—position paper on U.S. gas resources: American Association of Petroleum Geologists Explorer, v. 10, no. 9, p. 9.

Fisher, W. L., 1989, Pursuing the geological sciences—surviving the present and readying for the future: South Texas Geological Society Bulletin, v. 30, no. 1, p. 21–22.

Fisher, W. L., 1989, Role of the independent operator, *in* Proceedings of the Eighth Tertiary Oil Recovery Conference: University of Kansas, Contribution No. 10, p. 1–3.

Fisher, W. L. (chairman), 1989, Stabilizing U.S. oil prices: The University of Texas at Austin, Task Force on Oil Price Stabilization, report prepared for Governor William P. Clements, Jr., 65 p.,

Fisher, W. L., 1989, Turning difficulty into opportunity: Geotimes, v. 34, no. 11, p. 8–9.

Fogg, G. E., Lucia, F. J., and **Senger, R. K.,** 1989, Stochastic simulation of interwell-scale heterogeneity for improved prediction of sweep efficiency in a carbonate reservoir, *in* Second international reservoir characterization technical conference: National Institute for Petroleum and Energy Research/U.S. Department of Energy, p. 1–30.

Folk, R. L., 1989, Internal structuring of quartz as revealed by boiling concentrated hydrofluoric acid: Journal of Geological Education, v. 37, p. 250–260.

Galloway, W. E., 1989, Depositional framework and hydrocarbon resources of the early Miocene (Fleming) episode, northwest Gulf Coast Basin, *in* Hunt, M. C., and Doenges, S. V., eds., Studies related to continental margins: Marine Geology, v. 90, p. 19–29.

Galloway, W. E., 1989, Genetic stratigraphic sequences in basin analysis I: architecture and genesis of flooding-surface bounded depositional units: American Association of Petroleum Geologists Bulletin, v. 73, no. 2, p. 125–142.

Galloway, W. E., 1989, Genetic stratigraphic sequences in basin analysis II: application to northwest Gulf of Mexico Cenozoic basin: American Association of Petroleum Geologists Bulletin, v. 73, no. 2, p. 143–154.

Galloway, W. E., and **Morton, R. A.,** 1989, Geometry, genesis, and reservoir characteristics of shelf sandstone facies, Frio Formation (Oligocene), Texas Coastal Plain, *in* Morton, R. A., and Nummedal, Dag, eds., Shelf sedimentation, shelf sequences and related hydrocarbon accumulation: Gulf Coast Section, Society of Economic Paleontologists and Mineralogists Foundation 7th Annual Research Conference Proceedings, p. 89–115.

Hamilton, D. S., and **Galloway, W. E.,** 1989, New exploration techniques in the analysis of diagenetically complex reservoir sandstones, Sydney Basin, NSW: Australian Petroleum Exploration Association Journal, v. 29, pt. 1, p. 235–257.

Hellinger, S. J., **Sclater, J. G.,** and Giltner, J., 1989, Mid-Jurassic through mid-Cretaceous extension in the central graben of the North Sea, part 1: estimates from subsidence: Basin Research, v. 1, p. 191–200.

Henry, C. D., 1989, Late Cenozoic Basin and Range structure in western Mexico adjacent to the Gulf of California: Geological Society of America Bulletin, v. 101, p. 1147–1156.

Henry, C. D., and Price, J. G., 1989, The Christmas Mountains caldera complex, Trans-Pecos Texas—geology and development of a laccocaldera: Bulletin of Volcanology, v. 52, p. 97-112.

Henry, C. D., and Price, J. G., 1989, Geology, *in* Bedinger, M. S., Sargent, K. A., and Langer, W. H., Studies of geology and hydrology in the Basin and Range province, southwestern United States, for isolation of high-level radioactive waste—characterization of the Trans-Pecos region, Texas: U.S. Geological Survey Professional Paper 1370-B, p. B4–B22.

Henry, C. D., Price, J. G., Parker, D. F., and Wolff, J. A., 1989, Excursion 9A: Mid-Tertiary silicic alkalic magmatism of Trans-Pecos Texas: rheomorphic tuffs and extensive silicic lavas: New Mexico Bureau of Mines and Mineral Resources Memoir 46, p. 231–274.

Henry, C. D., Price, J. G., and Sargent, K. A., 1989, Quaternary tectonism, in Bedinger, M. S., Sargent, K. A., and Langer, W. H., Studies of geology and hydrology in the Basin and Range province, southwestern United States, for isolation of high-level radioactive waste—characterization of the Trans-Pecos region, Texas: U.S. Geological Survey Professional Paper 1370-B, p. B26–B30.

Hentz, T. F., 1989, Depositional environments of the Early Permian coastal plain, North-Central Texas: a synopsis, *in* Hook, R. W., ed., Permo-Carboniferous vertebrate paleontology, lithostratigraphy, and depositional environments of North-Central Texas: 49th Annual Meeting of the Society of Vertebrate Paleontology, Field Trip Guidebook No. 2, p. 22–39.

Hentz, T. F., 1989, Permo-Carboniferous lithostratigraphy of the vertebrate-bearing Bowie and Wichita Groups, North-Central Texas, *in* Hook, R. W., ed., Permo-Carboniferous vertebrate paleontology, lithostratigraphy, and depositional environments of North-Central Texas: 49th Annual Meeting of the Society of Vertebrate Paleontology, Field Trip Guidebook No. 2, p. 1–21.

Hentz, T. F., 1989, Stop 2—Archer City Formation stratotype, Archer City Formation, Bowie Group, Wolfcampian Series, *in* Hook, R. W., ed., Permo-Carboniferous vertebrate paleontology, lithostratigraphy, and depositional environments of North-Central Texas: 49th Annual Meeting of the Society of Vertebrate Paleontology, Field Trip Guidebook No. 2, p. 56–64.

Hentz, T. F., and **Henry, C. D.,** 1989, Evaporite-hosted native sulfur in Trans-Pecos Texas: relation to late-phase Basin and Range deformation: Geology, v. 17, p. 400–403.

Hovorka, S. D., 1989, Depth evolution of the Delaware Basin—Castile/Salado transition, *in* Harris, P. M., and Grover, G. A., eds., Subsurface and outcrop examination of the Capitan Shelf Margin, north Delaware Basin: Society of Economic Paleontologists and Mineralogists Core Workshop No. 13, p. 441–449.

Hunt, M. C., and **Doenges, S. V.,** eds., 1989, Studies related to continental margins: Marine Geology, v. 90, no. 1/2, Special Issue, 147 p.

Hunt, M. C., **Doenges, S. V.,** and **Stubbs, G. S.,** eds., 1989, Second symposium on studies related to continental margins—a summary of year-three and year-four activities: sponsored by Minerals Management Service, U.S. Department of the Interior, and Continental Margins Committee, Association of American State Geologists, Program and Abstracts, 34 p.

Jackson, M. L. W., and **Ambrose, W. A.,** 1989, Influence of reservoir heterogeneity on gas-resource potential for geologically based infill drilling, Brooks and I-92 reservoirs, Frio Formation, South Texas: Gulf Coast Association of Geological Societies Transactions, v. 39, p. 127–140.

Jackson, M. P. A., and Talbot, C. J., 1989, Anatomy of mushroom-shaped diapirs: Journal of Structural Geology, v. 11, no. 1/2, p. 211–230.

James, E. W., 1989, Southern extension of the Independence dike swarm of eastern California: Geology, v. 17, p. 587–590.

Kaiser, W. R., 1989, Texas—description of seams, *in* Keystone coal industry manual: Stamford, Connecticut, Maclean Hunter, p. 571–578.

Kaiser, W. R., and **Ayers, W. B., Jr.,** 1989, Hydrologic indicators of gas producibility: Gas Research Institute Coalbed Methane Workshop, Technical Session I, Part IV, 18 p.

Kaiser, W. R., and Swartz, T. E., 1989, Fruitland Formation hydrology and producibility of coalbed methane in the San Juan Basin, New Mexico and Colorado: The University of Alabama, School of Mines and Energy Development, Proceedings of the 1989 Coalbed Methane Symposium, No. 8926, p. 87–97.

Kerans, Charles, and Donaldson, J. A., 1989, Deepwater conical stromatolite reef, Sulky Formation (Dismal Lakes Group), Middle Proterozoic, Northwest Territories, *in* Geldsetzer, H. H. J., James, N. P., and Tebbutt, G. E., eds., Reefs, Canada and adjacent area: Canadian Society of Petroleum Geologists Memoir 13, p. 81–88.

Kerans, Charles, and **Lucia, F. J.,** 1989, Recognition of second, third, and fourth/fifth order scales of cyclicity in the El Paso Group and their relation to genesis and architecture of Ellenburger reservoirs, *in* Cunningham, B. K., and Cromwell, D. W., eds., The lower Paleozoic of West Texas and southern New Mexico—modern exploration concepts: Permian Basin Section, Society of Economic Paleontologists and Mineralogists Publication No. 89-31, p. 105–110.

Kittridge, M. G., Lake, L. W., **Lucia, F. J.,** and **Fogg, G. E.,** 1989, Outcrop-subsurface comparisons of heterogeneity in the San Andres Formation: Society of Petroleum Engineers Paper No. 19596, p. 259–273.

Kreitler, C. W., 1989, Distribution and identification of sources of nitrate in ground water, Texas, *in* Jensen, Ric, and Dunagan, Christine, Managing Texas' waters: stewardship in a regulatory environment: Proceedings of the 22nd Water for Texas Conference, p. 192–193.

Kreitler, C. W., 1989, Hydrogeology of sedimentary basins: Journal of Hydrology, v. 106, p. 29–53.

Kreitler, C. W., Akhter, M. S., and Donnelly, A. C. A., 1989, Hydrologic-hydrochemical characterization of Texas Gulf Coast saline formations used for deep-well injection of chemical wastes: Underground Injection Practice Research Foundation, Proceedings of International Symposium on Class I & II Injection Well Technology, p. 177–197.

Langford, R. P., 1989, Fluvial-aeolian interactions: part I, modern systems: Sedimentology, v. 36, p. 1023-1035.

Langford, R. P., and Chan, M. A., 1989, Fluvial-aeolian interactions: part II, ancient systems: Sedimentology, v. 36, p. 1037-1051.

Laubach, S. E., 1989, Paleostress directions from the preferred orientation of closed microfractures (fluid-inclusion planes) in sandstone, East Texas basin, U.S.A.: Journal of Structural Geology, v. 11, no. 5, p. 603–611.

Laubach, S. E., Reynolds, S. J., Spencer, J. E., and Marshak, Stephen, 1989, Progressive deformation and superposed fabrics related to Cretaceous crustal underthrusting in western Arizona, U.S.A.: Journal of Structural Geology, v. 11, no. 6, p. 735–749.

Laubach, S. E., Tye, R. S., Dutton, S. P., and **Herrington, K. L.,** 1989, Geological analyses of the Travis Peak Formation, *in* Staged Field Experiment No. 2, Application of advanced geological, petrophysical and engineering technologies to evaluate and improve gas recovery from low permeability sandstone reservoirs, Travis Peak Formation, North Appleby field, Nacogdoches County, Texas, Volume 1: CER Corporation and S. A. Holditch and Associates, Inc., report no. GRI-89/0140 prepared for Gas Research Institute, p. 42–90.

Lucia, F. J., and **Fogg, G. E.,** 1989, Geologic/stochastic mapping of heterogeneity in a carbonate reservoir: Dune (Grayburg) field, Crane County, Texas: Society of Petroleum Engineers Paper No. 19597, p. 275–283.

Major, R. P., and **Holtz, M. H.,** 1989, Effects of geologic heterogeneity on waterflood efficiency at Jordan field, University Lands, Ector and Crane Counties, Texas: Transactions of the 1989 Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Formation Evaluation and Reservoir Geology, Paper No. 19874, p. 633–640.

Martel, S. J., and Pollard, D. D., 1989, Mechanics of slip and fracture along small faults and simple strike-slip fault zones in granitic rock: Journal of Geophysical Research, v. 94, no. B7, p. 9417–9428.

Moore, C. H., and **Bebout, D. G.,** 1989, Carbonate rock sequences from the Cretaceous of Texas—San Antonio to Austin, Texas: 28th International Geological Congress, Field Trip Guidebook T376, 47 p.

Morton, R. A., and **Jirik, L. A.,** 1989, Origin, depositional pattern and reservoir characteristics of middle Miocene shallow-marine sandstones, offshore south Texas, *in* Morton, R. A., and Nummedal, Dag, eds., Shelf sedimentation, shelf sequences and related hydrocarbon accumulation: Gulf Coast Section, Society of Economic Paleontologists and Mineralogists Foundation 7th Annual Research Conference Proceedings, p. 143–162.

Morton, R. A., and Nummedal, Dag, eds., 1989, Shelf sedimentation, shelf sequences and related hydrocarbon accumulation: Gulf Coast Section, Society of Economic Paleontologists and Mineralogists Foundation 7th Annual Research Conference Proceedings, 211 p.

Mullican, W. F., III, Kreitler, C. W., Senger, R. K., and **Fisher, R. S.,** 1989, Truly deep saturated zone investigations at the proposed low-level radioactive waste disposal site for Texas, *in* Proceedings of the Third National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods: National Water Well Association, p. 447–461.

Nativ, Ronit, and Gutierrez, G. N., 1989, Hydrogeology and hydrochemistry of Cretaceous aquifers, Southern High Plains, U.S.A.: Journal of Hydrology, v. 108, p. 79–109.

Nativ, Ronit, **Kreitler, C. W.,** and **Mullican, W. F., III,** 1989, Active recharge into aquifers in the arid Trans-Pecos region, Texas, *in* Groundwater recharge processes in an arid environment: University of Arizona, Department of Hydrology and Water Resources, workshop held February 1987, [5 p.].

Paine, J. G., Morton, R. A., and **White, W. A.,** 1989, Preliminary assessment of nonfuel minerals on the Texas continental shelf, *in* Proceedings: Ninth Annual Gulf of Mexico Information Transfer Meeting, October 1988: New Orleans, U. S. Department of the Interior, Minerals Management Service, prepared under MMS contract no. 14-12-0001-30305, OCS Study/ MMS89-0060, p. 111-115.

Pilkey, O. H., **Morton, R. A.,** Kelley, J. T., and Penland, Shea, 1989, Coastal land loss: American Geophysical Union, Short Course in Geology, v. 2, 73 p.

Playford, P. E., Hurley, N. F., **Kerans, Charles,** and Middleton, M. F., 1989, Reefal platform development, Devonian of the Canning Basin, western Australia, *in* Controls on carbonate platform and basin development: Society of Economic Paleontologists and Mineralogists Special Publication No. 44, p. 187–202.

Posey, H. H., and **Fisher, R. S.,** 1989, A sulfur and strontium isotopic investigation of Lower Permian anhydrite, Palo Duro Basin, Texas, U.S.A.: Applied Geochemistry, v. 4, p. 395–407.

Price, J. G., **Henry, C. D.,** and Brady, B. T., 1989, Mineral and energy resources, in Bedinger, M. S., Sargent, K. A., and Langer, W. H., Studies of geology and hydrology in the Basin and Range province, southwestern United States, for isolation of high-level radioactive waste—characterization of the Trans-Pecos region, Texas: U.S. Geological Survey Professional Paper 1370-B, p. B38–B43.

Reynolds, S. J., Spencer, J. E., Asmeram, Yemane, DeWitt, Ed, and **Laubach, S. E.,** 1989, Early Mesozoic uplift in west-central Arizona and southeastern California: Geology, v. 17, no. 3, p. 207–211.

Reynolds, S. J., Spencer, J. E., **Laubach, S. E.,** Cunningham, Dickson, and Richard, S. M., 1989, Geologic map, geologic evolution, and mineral deposits of the Granite Wash Mountains, west-central Arizona: Arizona Geological Survey Open-File Report 89-4, 44 p.

Rosencrantz, E., **Sclater, J. G.,** and Boerner, S. T., 1989, Basement depths and heat flow in the Yucatan Basin and Cayman Trough, Northwestern Caribbean: implications for basin ages, *in* Wright, J. A., and Louden, K. E., eds., Handbook of seafloor heat flow: Boca Raton, Florida, CRC Press, p. 257–276.

Royer, J.-Y., **Sclater, J. G.,** and Sandwell, D., 1989, A preliminary tectonic fabric chart of the Indian Ocean, *in* Brune, J. B., ed., Proceedings, Indian Academy of Sciences: Earth and Planetary Sciences, v. 98, no. 1, p. 7–24.

Rubin, J. N., Henry, C. D., and Price, J. G., 1989, Hydrothermal zircons and zircon overgrowths, Sierra Blanca Peaks, Texas: American Mineralogist, v. 74, p. 865–869.

Ruppel, S. C., 1989, Summary of Mississippian stratigraphy in north and north-central Texas, *in* Mear, C. E., McNulty, C. L., and McNulty, M. E., eds., A symposium on the petroleum geology of Mississippian carbonates in north central Texas: Fort Worth Geological Society and Texas Christian University, p. 49–55.

Sclater, J. G., and Célérier, B., 1989, Errors in extension measurements from planar faults observed on multichannel seismic reflection lines: Basin Research, v. 1, p. 217–221.

Sclater, J. G., and Shorey, M., 1989, Mid-Jurassic through mid-Cretaceous extension in the central graben of the North Sea, part 2: estimates from faulting observed on a seismic reflection: Basin Research, v. 1, p. 201–215.

Sheridan, P. F., Slack, R. D., Ray, S. M., McKinney, L. W., Klima, E. F., and **Calnan, T. R.,** 1989, Biological components of Galveston Bay, *in* Galveston Bay: issues, resources, status, and management: U.S. Department of Commerce, National Oceanic and Atmospheric Administration Estuary-of-the-Month Seminar Series 13, p. 23–51.

Suter, J. R., **Morton, R. A.,** and Penland, Shea, 1989, Coastal depositional systems, Northwest Gulf of Mexico, Field Trip Guidebook T370 (New Orleans, Louisiana, to Houston, Texas): American Geophysical Union, 52 p.

Talbot, C. J., and **Jackson, M. P. A.,** 1989, Internal kinematics of salt diapirs: reply: American Association of Petroleum Geologists Bulletin, v. 73, no. 7, p. 946–950.

Tye, R. S., Dutton, S. P., Laubach, S. E., and **Finley, R. J.,** 1989, Geologic analysis of the Travis Peak tight gas sandstones: In Focus—Tight Gas Sands, v. 6, no. 1, p. 63–69.

Tye, R. S., Laubach, S. E., Dutton, S. P., and **Herrington, K. L.,** 1989, The role of geology in characterizing low-permeability sandstones, North Appleby field, East Texas Basin: Society of Petroleum Engineers, Proceedings, 1989 SPE Joint Rocky Mountain Regional/Low Permeability Reservoirs Symposium and Exhibition, Paper 18964, p. 355–365.

Tyler, Noel, 1989, The economic potential of strategic infill drilling in the San Andres/Grayburg South Central Basin Platform play: Society of Petroleum Engineers, Proceedings, Hydrocarbon Economics and Evaluation Symposium, Paper 18929, p. 149–164.

Tyler, Noel, 1989, Reserve growth through characterization of heterogeneous reservoirs: the Texas experience: International Energy Agency, 10th International Workshop and Symposium, Proceedings Volume, p. 21.1–21.30.

Wermund, E. G., Morton, R. A., and Powell, Gary, 1989, Geology, climate, and water circulation of the Galveston Bay System, *in* Galveston Bay: issues, resources, status, and management: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Estuary-of-the-Month Seminar Series No. 13, p. 3–22.

Wermund, E. G., White, W. A., Calnan, T. R., and **Morton, R. A.,** 1989, Mapping offshore coastal areas: "The Submerged Lands of Texas Atlas"—a review: Ocean and Shoreline Management, v. 12, p. 411–426.

Abstracts

Ambrose, W. A., and **Tyler, Noel,** 1989, Facies heterogeneity, pay continuity, and infill potential in barrier-island, fluvial, and submarine fan reservoirs: examples from the Texas Gulf Coast and Midland Basin (abs.): American Association of Petroleum Geologists Bulletin, v. 73, no. 3, p. 328.

Ayers, W. B., Jr., 1989, Geologic and hydrologic controls on coalbed methane occurrence and producibility, Fruitland Formation, San Juan Basin (abs.): West Texas Geological Society Bulletin, v. 29, no. 2, p. 12.

Barnes, V. E., 1989, Origin of tektites (abs.): Meteoritics, v. 24, no. 4, p. 249–250.

Barnes, V. E., and Barnes, V. E., II, 1989, Comets and the origin of tektites (abs.): Meteoritics, v. 24, no. 4, p. 250.

Brown, L. F., Jr., 1989, Re-exploration of cratonic basins using passive-margin sequence-stratigraphic concepts: examples from upper Paleozoic rocks, eastern margin, Midland Basin (abs.): American Association of Petroleum Geologists Bulletin, v. 73, no. 3, p. 338.

Brown, L. F., Jr., 1989, A sequence-stratigraphic and systems-tract model of the Virgilian and Wolfcampian Series, Eastern Shelf and adjacent Midland Basin, Texas (abs.): Geological Society of America Abstracts with Programs, v. 21, no. 1, p. 5.

Brown, L. F., Jr., 1989, Use of sequence stratigraphy to define stratigraphic plays in Upper Pennsylvanian and Lower Permian lowstand systems tracts, North-Central Texas (abs.): American Association of Petroleum Geologists Bulletin, v. 73, no. 2, p. 255.

Calnan, T. R., 1989, Distribution and abundance of mollusks and polychaetes on the Texas inner shelf and their zoogeographic relationships (abs.): Texas Academy of Science, 92nd Annual Meeting, Abstracts of Papers Presented, abstract no. 103.

Coleman, Janet, and **Galloway, W. E.,** 1989, Sea level events associated with lower Oligocene Vicksburg Formation of Texas Gulf coastal plain, as determined from depositional systems analysis (abs.): American Association of Petroleum Geologists Bulletin, v. 73, no. 3, p. 345.

Collins, E. W., and **Raney, J. A., 1989,** Quaternary history of the Campo Grande fault of the Hueco Basin, Hudspeth and El Paso Counties, Trans-Pecos Texas (abs.): Geological Society of America, Abstracts with Programs, v. 21, no. 6, p. A202.

DuBar, J. R., 1989, Ecology and taphonomy of environmentally stressed non-marine molluscan populations, Grand Prairie Province, east-central Texas (abs.): American Malacological Union/Western Society of Malacologists Combined Annual Meeting, Program and Abstracts, p. 33.

Dutton, A. R., and **Senger, R. K.,** 1989, Geological evolution of Southern Great Plains (U.S.A.) regional ground-water flow system (abs.): 28th International Geological Congress, Abstracts Volume No. 1, p. 1–426.

Dutton, S. P., and **Diggs, T. N.,** 1989, Controls on permeability distribution in Lower Cretaceous Travis Peak Formation, East Texas (abs.): American Association of Petroleum Geologists Bulletin, v. 73, no. 3, p. 352.

Erwin, M. E., Long, L. E., and **Fisher, R. S.,** 1989, Rb-Sr ages of diagenesis of Mg-rich clay, Permian evaporite sequence, Palo Duro Basin, Texas Panhandle (abs.): Geological Society of America, Abstracts with Programs, v. 21, no. 6, p. A17.

Fisher, R. S., and **Mullican, W. F., III,** 1989, Hydrochemistry of ground water beneath a thick unsaturated zone, eastern Hueco Bolson, Trans-Pecos Texas (abs.): Geological Society of America, Abstracts with Programs, v. 21, no. 6, p. A41–A42.

Folk, R. L., and Noble, P., 1989, Aragonite, calcite, and bacteria from volcanic hot springs, Viterbo (Lazio), Italy (abs.), *in* Rezak, R., and Winsborough, B., eds., Texas-Mexico Stromatolite Field Conference Program with Abstracts and Field Trip Guidebook, p. 46.

Galloway, W. E., 1989, Genetic stratigraphic sequences: flooding-surface-bounded depositional units in terrigenous shelves and seaways (abs.): 28th International Geological Congress, Abstracts Volume No. 1, p. 525.

Galloway, W. E., and **Hamilton, D. S.,** 1989, Regional, three-dimensional permeability distribution within a diagenetically complex fluvial basin fill (abs.): American Association of Petroleum Geologists Bulletin, v. 73, no. 3, p. 357.

Galloway, W. E., and Liangqing, Xue, 1989, Fan-delta, braid delta and the classification of delta systems (abs.), *in* IAS international symposium on sedimentology related to mineral deposits abstracts: International Association of Sedimentologists, p. 58–59.

Guevara, E. H., and **Tyler, Noel,** 1989, Facies architecture of Spraberry submarine fan reservoirs (Permian), Midland Basin, Texas (abs.): American Association of Petroleum Geologists Bulletin, v. 73, no. 3, p. 359.

Gustavson, T. C., 1989, Paleovertisols of the Late Tertiary Fort Hancock Formation and the Tertiary-Quaternary Camp Rice Formation, Hueco Bolson, West Texas (abs.): Geological Society of America, Abstracts with Programs, v. 21, no. 6, p. A345.

Hamlin, H. S., 1989, Hydrocarbon production and potential of the distal Frio Formation, Texas Gulf Coast and offshore (abs.), *in* Hunt, M. C., Doenges, Susann, and Stubbs, G. S., eds., Second symposium on studies related to continental margins—a summary of year-three and year-four activities: sponsored by Minerals Management Service, U.S. Department of the Interior, and Continental Margins Committee, Association of American State Geologists, Program and Abstracts, p. 18.

Henry, C. D., Price, J. G., and **Rubin, J. N.,** 1989, Distinguishing strongly rheomorphic tuffs from extensive silicic lavas: implications from Trans-Pecos Texas (abs.): New Mexico Bureau of Mines and Mineral Resources, Continental Magmatism Abstracts Bulletin 131, p. 127.

Henry, C. D., Price, J. G., **Rubin, J. N.,** and **Laubach, S. E.,** 1989, The Bracks Rhyolite: a large-volume, extensive silicic lava of Trans-Pecos Texas (abs.): Geological Society of America Abstracts with Programs, v. 21, no. 1, p. 14.

Hook, R. W., Hotton, N., III, and **Hentz, T. F.,** 1989, Paleoenvironmental analysis of Lower Permian vertebrate-bearing deposits in North-Central Texas—preliminary report (abs.): Geological Society of America Abstracts with Programs, v. 21, no. 1, p. 15.

Jackson, M. L. W., and **Ambrose, W. A.,** 1989, Influence of reservoir heterogeneity on gas resource potential for geologically based infill drilling, Brooks and I-92 reservoirs,

Frio Formation, South Texas (abs.): American Association of Petroleum Geologists Bulletin, v. 73, no. 9, p. 1185.

Jackson, M. P. A., and Cramez, Carlos, 1989, Seismic recognition of salt welds in salt tectonics regimes (extended abs.), *in* Gulf of Mexico salt tectonics, associated processes and exploration potential: Society of Economic Paleontologists and Mineralogists, Gulf Coast Section, 10th Annual Research Conference Program and Extended and Illustrated Abstracts, p. 66–71.

Jackson, M. P. A., and Talbot, C. J., 1989, Salt canopies (extended abs.), *in* Gulf of Mexico salt tectonics, associated processes and exploration potential: Society of Economic Paleontologists and Mineralogists, Gulf Coast Section, 10th Annual Research Conference Program and Extended and Illustrated Abstracts, p. 72–78.

James, E. W., Silver, L. T., and Cotkin, S. J., 1989, Structural and tectonic observations from leg two of Cajon Pass drilling (abs.): Eos, v. 70, no. 15, p. 482.

Kerans, Charles, Holtz, M. H., and **Tyler, Noel,** 1989, Contrasting styles of reservoir heterogeneity in Ellenburger Group carbonates, West Texas (abs.), *in* Cunningham, B. K., and Cromwell, D. W., eds., The lower Paleozoic of West Texas and southern New Mexico—modern exploration concepts: Permian Basin Section, Society of Economic Paleontologists and Mineralogists Publication No. 89-31, p. 131.

Kerr, D. R., and Konopka, E. H., 1989, The application of log-linear modeling to quantitative facies analysis (abs.): 28th International Geological Congress, Abstracts Volume No. 2, p. 2–178.

Kreitler, C. W., and **Senger, R. K.,** 1989, Guidelines for well head protection areas in confined aquifer settings (abs.): 28th International Geological Congress, Abstracts Volume No. 2, p. 266.

Laubach, S. E., 1989, Evolution of normal fault block shape in space and time (abs.), *in* Structural and tectonic modelling and its application to petroleum geology: Norwegian Petroleum Society, Abstracts, p. 24.

Laubach, S. E., 1989, Origin of extension fractures in sandstone from a passive margin basin (abs.): Leeds, England, The University of Leeds, Deformation mechanisms, rheology, and tectonics conference, proceedings volume, unpaginated.

Laubach, S. E., Baumgardner, R. W., Jr., Monson, E. R., Hunt, E., and Meador, K. J., 1989, Fracture detection in low-permeability reservoir sandstone: comparison of BHTV and FMS logs to core (abs.): American Association of Petroleum Geologists Bulletin, v. 73, no. 3, p. 378.

Laubach, S. E., and Boardman, S., 1989, Multiple generations of fluid inclusions in Cretaceous quartz veins from the Gulf of Mexico basin (abs.): Geological Society of America, Abstracts with Programs, v. 21, no. 6, p. A64.

Laubach, S. E., Hoak, T. E., **Dutton, S. P.,** and **Diggs, T. N.,** 1989, Coevolution of fracture pattern, rock mechanical properties, and diagenesis in a low-permeability gas reservoir sandstone, East Texas (abs.): Geological Society of America Abstracts with Programs, v. 21, no. 1, p. 16.

Laubach, S. E., Reynolds, S. J., and **Raney, J. A.,** 1989, Normal fault geometry: examples from above the Buckskin detachment fault, Arizona (abs.): Geological Society of America, Abstracts with Programs, v. 21, no. 6, p. A202.

Lucia, F. J., 1989, Integrating rock fabric into log analysis for permeability calculations (abs.), *in* Exploration exploitation engineering environmental—professional applications using computer based tools: Houston Geotech '89 Program Booklet, unpaginated.

Major, R. P., 1989, Depositionally and diagenetically controlled reservoir heterogeneity, Jordan field, University Lands, Ector and Crane Counties, Texas (abs.): West Texas Geological Society Bulletin, v. 29, no. 1, p. 14.

Major, R. P., 1989, Reservoir characterization of the East Penwell San Andres Unit, University Lands, West Texas (abs.): Society of Economic Paleontologists and Mineralogists, Permian Basin Section Newsletter, v. 3, no. 5, p. 3–4.

Major, R. P., and **Holtz, M. H.,** 1989, Effects of geologic heterogeneity on waterflood efficiency at Jordan field, University Lands, Ector and Crane Counties, Texas (abs.): American Association of Petroleum Geologists Bulletin, v. 73, no. 3, p. 385.

Major, R. P., and Wilber, R. J., 1989, Geochemistry, crystal habit, and cathodoluminescence of some marine magnesian calcite cements (abs.): Geological Society of America Abstracts with Programs, v. 21, no. 6, p. A259.

Milling, M. E., Lucia, F. J., Hocott, C. R., Miller, M. A., and Neitzel, E. B., 1989, Geoscience oil and gas recovery research: a new perspective (abs.): American Association of Petroleum Geologists Bulletin, v. 73, no. 9, p. 1167.

Morton, R. A., 1989, Pliocene-Pleistocene hydrocarbon plays of offshore Texas (abs.): American Association of Petroleum Geologists Bulletin, v. 73, p. 394.

Morton, R. A., 1989, Reservoir characterization of selected distal Frio Formation fields, offshore Texas (abs.), *in* Hunt, M. C., Doenges, Susann, and Stubbs, G. S., eds., Second symposium on studies related to continental margins—a summary of year-three and year-four activities: sponsored by Minerals Management Service, U.S. Department of the Interior, and Continental Margins Committee, Association of American State Geologists, Program and Abstracts, p. 17.

Mullican, W. F., III, 1989, Subsidence and collapse at Boling salt dome—the results of multiple resource recovery and potential impact on toxic waste disposal (abs.): Houston Geological Society Bulletin, v. 31, no. 6, p. 10.

Pulich, W. M., and **White, W. A.,** 1989, Decline of submerged vascular plants in the Galveston Bay system: chronology and relationships to physical processes (abs.), *in* 10th Biennial International Estuarine Research Conference abstracts: Baltimore, Estuarine Research Federation, p. 65.

Reynolds, S. A., **Galloway, W. E.,** and Glasford, J. L., 1989, Genetic stratigraphic sequences in nonmarine basins (abs.): 28th International Geological Congress, Abstracts Volume No. 2, p. 691–692.

Seni, S. J., 1989, Salt tectonics on the continental slope, Green Canyon Area, northern Gulf of Mexico (abs.): Houston, Texas, Society of Exploration Geophysicists, Fifth Annual Gulf Coast Exploration and Development Meeting and Exposition, p. 21.

Seni, S. J., and **Jackson, M. P. A.,** 1989, Counter-regional growth faults and salt sheet emplacement, northern Gulf of Mexico (extended abs.), *in* Gulf of Mexico salt tectonics, associated processes and exploration potential: Society of Economic Paleontologists and Mineralogists, Gulf Coast Section, 10th Annual Research Conference Program and Extended and Illustrated Abstracts, p. 116–121.

Silver, L. T., and **James, E. W.,** 1989, The Cajon Pass scientific drillhole: keyhole to southern California geologic evolution (abs.): Eos, v. 70, no. 15, p. 481.

Silver, L. T., **James, E. W.,** and Cotkin, Spencer, 1989, Cretaceous and Cenozoic orogenic events in the southwestern Mojave Desert and San Bernardino Mountains evident in the Cajon Pass deep drillhole (abs.): Geological Society of America Abstracts with Programs, v. 21, p. 143.

Silver, L. T., **James, E. W.,** Cotkin, S. J., and Chappell, Bruce, 1989, Preliminary lithologic column from leg two of Cajon Pass drilling (abs.): Eos, v. 70, no. 15, p. 482.

Tye, R. S., 1989, Fluvial sandstone reservoirs of Travis Peak (Hosston) Formation, East Texas Basin (abs.): American Association of Petroleum Geologists Bulletin, v. 73, no. 3, p. 421.

Tyler, Noel, 1989, Additioual recovery from mature reservoirs—promise of integrated geoscience characterization (abs.): American Association of Petroleum Geologists Bulletin, v. 73, no. 9, p. 1176.

Tyler, Noel, and **Finley, R. J.,** 1989, Architectural styles and reservoir performance—a predictive tool (abs.): American Association of Petroleum Geologists Bulletin, v. 73, no. 3, p. 421.

Tyler, Noel, and **Finley, R. J.,** 1989, Geologic modeling of reservoirs for improved oil and gas recovery (expanded abstract), *in* Expanded abstracts with biographies: Society of Exploration Geophysicists, 59th Annual International SEG Meeting, SEG/AAPG Workshop on Exploration Applications of Geologic Modeling, 1989 Technical Program, v. 2, p. 1345–1347.

Vendeville, B. C., 1989, Scaled experiments on the interaction between salt flow and overburden faulting during syndepositional extension (extended abs.), *in* Gulf of Mexico salt tectonics, associated processes and exploration potential: Society of Economic Paleontologists and Mineralogists, Gulf Coast Section, 10th Annual Research Conference Program and Extended and Illustrated Abstracts, p. 131–136.

Lectures and Public Addresses

William A. Ambrose

"Infill potential of fluvial gas reservoirs in LaGloria field, South Texas": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 391), Austin, Texas.

Walter B. Ayers, Jr.

"Evaluation of geologic and hydrologic factors critical to coalbed methane occurrence and production, Fruitland Formation, San Juan Basin": presented to the Coalbed Methane Forum, Lakewood, Colorado.

"Geologic controls on coalbed methane occurrence and recovery, north-central San Juan Basin": presented to the Houston Producer's Forum, Houston, Texas.

"Geologic and hydrologic controls on the occurrence and producibility of coalbed methane, Fruitland Formation, San Juan Basin": presented to the Roswell Geological Society, Roswell, New Mexico.

"Geologic evaluation of critical production parameters for coalbed methane resources in the San Juan Basin": presented to the Gas Research Institute, Natural Gas Supply Project Advisors Meeting, Birmingham, Alabama.

Virgil E. Barnes

"Geology as a career": presented to the Burtsfield School, 5th grade class, 1989-90 Career Education Series, West Lafayette, Indiana.

Robert W. Baumgardner, Jr.

"Geomorphology of the low-level radioactive waste study area, Hudspeth County, Texas": presented to the Texas Low-Level Radioactive Waste Disposal Authority, Austin, Texas.

Alan R. Dutton

"Application of hydrogeochemistry and stable isotopes in confirming conceptual models of ground-water flow": presented to the University of Rochester, Department of Geological Sciences (Lyons Lectureship), Rochester, New York.

"The instantaneous-profile hydraulic conductivity test as a teaching tool for vadose-zone hydrology": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 381D), Austin, Texas.

Shirley P. Dutton

"Cementation and burial history of a low-permeability quartzarenite, Lower Cretaceous Travis Peak Formation, East Texas": presented to the University of New Orleans, Department of Geology, New Orleans, Louisiana.

"Bureau of Economic Geology studies on tight gas sandstones": 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 Society of Professional Well Log Analysts, Shreveport, Louisiana.

Robert J. Finley

"Natural gas: a substantial resource at moderate prices": presented to The Western States Land Commissioners Association, San Diego, California.

"Reevaluating the U.S. natural gas resource base: reserves, resources, and reserve growth": presented to the Dallas Energy Council, Annual Energy Education Day, Dallas, Texas.

"Reserve growth in gas reservoirs: more gas from existing fields with an example from the Frio Formation, South Texas": presented to the Corpus Christi Geological Society, Corpus Christi, Texas.

"Secondary natural gas recovery: targeted technology applications for infield reserve growth, a status report":

presented to the U.S. Department of Energy, Natural Gas Research and Development Contractors Review Meeting, Morgantown, West Virginia, and to the Gas Research Institute, Natural Gas Supply Project Advisors Meeting, Chicago, Illinois.

"Natural gas: reserves, supply, and demand: an assessment of the natural gas resource base of the United States": presented to the Clean Air Texas/Texas Environmental Coalition, Cleaner Air for Texas Using an Alternative Fuel: Natural Gas Conference, Dallas, Texas.

"Natural gas: a national supply overview": presented to the University of Southern California, Jesse M. Unruh Institute of Politics Symposium (Natural Gas: Meeting California's Energy Needs and Air Quality Goals), Los Angeles, California.

"Gas reserve growth: a new source of natural gas supply": presented to the North American Natural Gas Supply and Markets Conference, Denver, Colorado.

R. Stephen Fisher

"Clay mineral diagenesis of marine evaporites": presented to The University of Texas at Austin, Department of Geological Sciences, Soft Rock Seminar, Austin, Texas.

"Results of ground-water hydrogeochemical investigations in the Fort Hancock area, Hudspeth County, Texas": presented to the Texas Low-Level Radioactive Waste Disposal Authority, Board of Directors, Austin, Texas.

William L. Fisher

"Natural gas, more plus than minus": presented to the Texas Independent Producers and Royalty Owners Association, 1989 mid-year meeting, Austin, Texas.

"The Permian Basin in 1992": presented to the Permian Basin Landmen's Association, Midland, Texas.

"Oil and gas resources: future options from a historical perspective": presented to the National Conference of State Legislators, U.S.–Canada Legislative Symposium, San Antonio, Texas.

"Outlook for oil and gas": presented to the Austin Geological Society, Austin, Texas.

"International oil markets": presented to the Massachusetts Institute of Technology, Center for Energy Policy Research, Cambridge, Massachusetts.

"A new look at oil and gas potential": presented to the Abilene Geological Society, Abilene, Texas.

"Assessment of U.S. natural gas resource base": presented as the keynote address to the U.S. Department of Energy, Unconventional Gas Research and Development Conference, Morgantown, West Virginia.

"Changing perspectives of the U.S. oil and gas resource base": presented to the American Association of Petroleum Landmen, 1989 annual meeting, Anaheim, California.

"New oil from old fields: an exciting new frontier": presented to Trinity University, Annual National Conference on Undergraduate Research, San Antonio, Texas.

"Natural gas resources": presented to the American Gas Association, Supply Task Force Meeting, Naples, Florida.

"New approaches to gas resource evaluation": presented to the American Gas Association, 1989 annual meeting, Hilton Head, South Carolina.

"The independent oil and gas operators: future challenges and opportunities": presented as the keynote address to The University of Kansas, Oil Recovery Conference, Wichita, Kansas.

"The new promise of natural gas": presented to the American Association of Petroleum Geologists, Division of Professional Affairs, 1989 annual meeting, San Antonio, Texas.

"Strategies for energy exploration and development": presented to the American Association of Petroleum Geologists, Energy Minerals Division, 1989 annual meeting, San Antonio, Texas.

"Search for the subtle trap": presented as the keynote address to the West Texas Geological Society, Symposium on Search for the Subtle Trap, Midland, Texas.

"Oil and gas potential of the U.S. lower 48 states": presented to the Society of Exploration Geophysicists, Symposium on Exploration Economics, 1989 annual meeting, Dallas, Texas.

"Independents: implication of the remaining oil and gas resource base": presented to the Independent Petroleum Association of America, 1989 annual meeting, San Francisco, California.

"Changing perceptions of U.S. resource base": presented as the keynote address to the IBM Exploration and Production Software Symposium, Houston, Texas.

"Extended reserve growth for natural gas": presented to the Denver-Julesburg Petroleum Association, Colorado Natural Gas Conference, Denver, Colorado.

"Natural gas: reaching stability": presented to the Gas Daily Conference on Outlook for Gas Prices, Houston, Texas.

"Geological research: unique role of the state geological surveys": presented to the Geological Society of America, Symposium on Geologic Research and Public Policy, 1989 annual meeting, St. Louis, Missouri.

Robert L. Folk

"What controls aragonite vs. calcite precipitation in Viterban hot springs: comparison of hot springs bacteria with Triassic bacteria from Italy": presented to The University of Texas at Austin, Department of Geological Sciences, Soft Rock Seminar, Austin, Texas.

"HF etching of quartz and the most fantastic field day of my life": presented to the Austin Geological Society, Austin, Texas, and to Wichita State University, Geology Department, Wichita, Kansas.

"Internal structure of quartz revealed by etching in HF": presented to the New Mexico Bureau of Economic Geology and School of Mines, Socorro, New Mexico, and to The University of Texas at Austin, Department of Geological Sciences, Hard Rock Seminar, Austin, Texas.

"Hot spring deposits of Viterbo, Italy, and their bacteria": presented to the Stromatolite Conference, Austin, Texas.

William E. Galloway

"Lithostratigraphic correlation," "Occurrence of petroleum in alluvial fan, fluvial, delta, and slope/fan systems," "Depositional and structural styles of prograding basin margins," "Petroleum geology of the Gulf Coast Basin," and "Terrigenous clastic depositional systems and sequences": lecture series presented to the China Research Institute of Petroleum Exploration and Development and at China University of Geosciences, Beijing, Peoples Republic of China.

"Genetic stratigraphic sequences": presented to the British Geological Survey, Edinburg, Scotland.

"Genetic stratigraphic sequences: flooding-surface-bounded depositional units in terrigenous shelves and seaways": presented as the keynote lecture at the International Geological Congress, Session B11, Washington, D.C.

"Origin and evolution of submarine canyons in progradational clastic continental margins": presented to the South Texas Geological Society, San Antonio, Texas.

L. Edwin Garner

"Geology of the SSC site, Ellis County, Texas": presented to the Superconducting Super Collider Underground Technology Advisory Panel, San Francisco, California.

Edgar H. Guevara

"Geological characterization of oil reservoirs in the Benedum Spraberry Waterflood Unit, Midland Basin": presented to Marathon Oil Company, Midland, Texas.

Thomas C. Gustavson

"Stratigraphy of the Tertiary Fort Hancock and Tertiary-Quaternary Camp Rice Formations, Rio Grande Rift (Hueco Bolson), West Texas and Chihuahua, Mexico": presented to The University of Texas at Austin, Department of Geography (Geography 386C), Austin, Texas.

Christopher D. Henry

"Temporal and geochemical variations within the Trans-Pecos magmatic province": presented to Sul Ross State University, Workshop on Geochemistry of Trans-Pecos Magmatism, Alpine, Texas.

Claude R. Hocott

"Potential for improved mobile oil recovery and enhanced oil recovery": presented to the National Academy of Sciences, Liquid Fuels Committee, Washington, D.C.

Susan D. Hovorka

"Description of porosity in Devonian chert, West Texas": presented to Mobil Oil Company, Midland, Texas.

Martin P. A. Jackson

"A revolution in salt tectonics: allochthonous salt sheets and rafts": presented to the University of Uppsala, Institute of Geology, Uppsala, Sweden.

"International programs in the modeling of diapirism": presented to the University of Uppsala, Institute of Geology, Uppsala, Sweden.

"Background: current state of physical modeling," "Centrifuge modeling of salt tectonics," "Piercement of diapiric stocks and walls," "Diapiric allochthonous tongues," and "Faulting and diapirism during gliding/spreading": presented to the Industrial Associates of the Applied Geodynamics Laboratory, Austin, Texas.

"Salt canopies: surface, subsurface, theory, and experiment": presented to The University of Texas at Austin, Department of Geological Sciences, Hard Rock Seminar, Austin, Texas.

William R. Kaiser

"Hydrology of the Fruitland Formation": presented to the Coalbed Methane Committee, Farmington, New Mexico.

"Hydrologic parameters for the production of coalbed methane": presented to the Eastern Coalbed Methane Forum, Tuscaloosa, Alabama.

Charles Kerans

"Origin of reservoir compartmentalization in Lower Ordovician karstic dolostones, Ellenburger Group, West Texas": presented to the Graham Geological Society, Graham, Texas.

Dennis R. Kerr

"Sequence stratigraphy of Pennsylvanian to Lower Permian strata (upper Amsden Formation and Tensleep Sandstone), north-central Wyoming": presented to The University of Texas at Austin, Department of Geological Sciences, Soft Rock Seminar, Austin, Texas.

"Interpretation of eolian dune types: implications for reservoir compartmentalization with an example from the Permo-Pennsylvanian Tensleep Sandstone of north-central Wyoming": presented to San Diego State University, The Department of Geological Sciences, San Diego, California; UNOCAL Research Center, Brea, California; and Chevron Oil Field Research Laboratory, La Habra, California.

Charles W. Kreitler

"Hydrogeology of the Edwards aquifer": presented to the South Texas Land Owners Association, Hondo, Texas.

"Methods for determining degree of confinement for confined aquifers": presented to The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

"Determining the source of salinity in ground water with geochemical tracers": presented to the U.S. Environmental Protection Agency, Robert S. Kerr Laboratory, 1989 annual research meeting, Oklahoma City, Oklahoma.

"Wellhead protection strategies for confined aquifer settings": presented to the U.S. Environmental Protection Agency, Office of Ground Water Protection, Washington, D.C.

"Deep-well injection of chemical wastes, Texas Gulf Coast": presented to The University of Texas at Austin, Department of Environmental Health Engineering, Austin, Texas.

"Use of the petrographic microscope for rocks and minerals": presented to the Eanes Independent School District, Live Oak Adventure, Austin, Texas.

"Hydrogeology of large sedimentary basins": presented to the Weizmann Institute and Faculty of Agriculture, Hebrew University, Rohovot, Israel.

"Water chemistry as a tracer of ground-water flow systems": presented to the Israel Geological Survey, Jerusalem, Israel, and to Technion Institute, Haifa, Israel.

"Monoclinal carbonate plateaus as potential targets for ground-water exploration in desert environments": presented to the Blaustein Institute for Desert Research, Sde Boqer, Israel.

"Hydrology of large sedimentary basins: deep circulation of meteoric ground water": presented to Exxon Company, International, Houston, Texas.

Richard P. Langford

"Rocks and minerals": presented at the Becker Elementary School Science Day Fair, Austin, Texas.

Stephen E. Laubach

"Current research on prediction of fractures": presented to Exxon Production Research Company, Houston, Texas.

"Geometry of normal faults in layered rocks: examples from the Basin and Range province": presented to Exxon Production Research Company, Houston, Texas.

"Stratigraphy, diagenesis, and structure of the Travis Peak Formation and their effects on reservoir quality": presented to the Gas Research Institute Forum/Workshop in association with the Society of Petroleum Engineers, Gas Technology Symposium, Dallas, Texas.

"Analysis of fractures and in situ stress in reservoir rocks": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 391), Austin, Texas.

"Minor structures in distorting normal fault blocks": presented to the Industrial Associates of the Applied Geodynamics Laboratory, Austin, Texas.

"Application of borehole-imaging logs to fracture evaluation in low-permeability gas reservoirs" and "Origin, distribution, and effect on production of natural fractures in a low-permeability gas reservoir with extensive quartz cement": presented to the Society of Petroleum Engineers, Naturally Fractured Reservoir Forum, Crested Butte, Colorado.

"Aspects of geologic and geophysical evaluation of subsurface fractures" and "Patterns in the development of extensional fault blocks": presented to Norsk Hydro a.s. Research, Bergen, Norway.

F. Jerry Lucia

"Improved recovery of the remaining oil resource base in the Permian Basin": presented to the Dallas Energy Council, Annual Energy Education Day, Dallas, Texas.

"Integrating rock fabric into log analysis for permeability calculations": presented to Houston Geotech '89, Houston, Texas.

"Current trends in converting geological descriptions into engineering parameters": presented to the Society of Petroleum Engineers, Forum on Reservoir Management, Crested Butte, Colorado.

"Trends in oil and gas recovery in the 1990's": presented to the American Institute of Professional Geologists, 1989 annual meeting, Houston, Texas.

Richard P. Major

"Reservoir characterization of the East Penwell San Andres Unit, University Lands, West Texas": presented to the Society of Economic Paleontologists and Mineralogists, Permian Basin Section, Midland, Texas.

"Depositionally and diagenetically controlled reservoir heterogeneity, Jordan field, University Lands, Ector and Crane Counties, Texas": presented to the West Texas Geological Society, Midland, Texas.

"Effects of geologic heterogeneity on waterflood efficiency at Jordan field, University Lands, Ector and Crane Counties, Texas": presented to ARCO Oil and Gas Company, Research Department, Plano, Texas.

"Cathodoluminescence and marine diagenesis in magnesian calcite": presented to The University of Texas at Dallas, Programs in Geosciences, Richardson, Texas.

"Reservoir characterization on University Lands": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 391), Austin, Texas.

Mary W. McBride

"Rocks and fossils in your backyard: what story do they tell?": presented to Dripping Springs Elementary School, 4th and 5th grade classes, Dripping Springs, Texas.

"Where in the world are you? or Map-readers know how to get there": presented to Cook Elementary School, 5th grade classes, Austin, Texas.

"Geology as a career": presented to Cedar Park High School, Geology classes, Cedar Park, Texas.

"You can't live without rocks": presented to Burnet Junior High School, Earth Science classes, Austin, Texas.

"Geology as a career": presented to Wiley College science workshop, Marshall, Texas.

"The Bureau of Economic Geology as a resource for fossil and paleontological clubs": presented to the Central Texas Paleontological Club, Austin, Texas.

"The Bureau of Economic Geology as a resource for gem and mineral clubs": presented to the Williamson County Gem and Mineral Club, Georgetown, Texas.

Marcus E. Milling

"Applications of seismic stratigraphic sequence analysis in oil and gas exploration": presented to Texaco International, Austin, Texas.

"Deepwater submarine fan exploration models": presented to Mobil Oil International, Caracas, Venezuela.

"Proposed Geoscience Institute oil and gas recovery research initiative": presented to the Society of Petroleum Engineers, Reservoir and Recovery Forum meeting, San Antonio, Texas.

"Interdisciplinary oil and gas recovery research": presented to the Society of Exploration Geophysicists, 1989 annual meeting, Dallas, Texas.

"Interdisciplinary oil and gas recovery research: a new perspective": presented to the American Institute of Professional Geologists, 1989 annual meeting, Washington, D.C.

Robert A. Morton

"Interactions of storms, seawalls, and beaches of the Texas coast": presented to the U.S. Army Corps of Engineers, Coastal Engineering Research Board, Wilmington, North Carolina.

"Responses to beach erosion in Texas": presented to the Eighth Annual State Submerged Lands Conference, South Padre Island, Texas.

"Plio-Pleistocene depositional systems and related hydrocarbon accumulation, Texas continental shelf": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 380), Austin, Texas.

"Coastal land loss and its social implications": presented to The University of Texas at Austin, School of Architecture and Planning (CRP 388K), Austin, Texas.

William F. Mullican III

"Results of saturated-zone hydrologic investigations in the Fort Hancock area, Hudspeth County, Texas": presented to the Texas Low-Level Radioactive Waste Disposal Authority, Board of Directors, Austin, Texas.

Jay A. Raney

"Regional setting and geologic history of an area near Fort Hancock, Texas": presented to the Texas Low-Level Radioactive Waste Disposal Authority, Board of Directors, Austin, Texas.

Stephen C. Ruppel

"Reservoir heterogeneity in Permian carbonates: depositional and diagenetic controls": presented to the Royal Dutch Shell Exploration and Production Laboratory, Rijswijk, The Netherlands.

"Diagenetic evolution of Permian carbonates, southwestern United States": presented to Vrei Universiteit, Department of Geology, Amsterdam, The Netherlands.

"Analysis of depositional systems and diagenesis in the San Andres Formation, Texas": presented to The University of Texas at Austin, Department of Geological Sciences, Soft Rock Seminar, Austin, Texas.

"Bureau of Economic Geology reservoir characterization studies": presented to the Texas Higher Education Coordinating Board, Salado, Texas.

"Controls on reservoir development: Devonian, West Texas": presented to Mobil Oil Company, Midland, Texas.

"Summary of Mississippian stratigraphy in North and North-Central Texas": presented at the Symposium on the Petroleum Geology of Mississippian Carbonates in North-Central Texas, Fort Worth, Texas.

Bridget R. Scanlon

"Analysis of unsaturated flow in the Chihuahuan desert, West Texas": presented to the University of Rochester, Department of Geological Sciences, Rochester, New York.

"Summary of unsaturated-zone studies in the Chihuahuan desert related to low-level radioactive waste disposal": presented to the Texas Low-Level Waste Disposal Authority, Board of Directors, Austin, Texas.

Daniel D. Schultz-Ela

"Belt tightening in the Archean: reconstructions of deformation in Minnesota greenstones": presented to Macalester College, St. Paul, Minnesota, and to The University of Texas at Austin, Department of Geological Sciences, Technical Sessions, Austin, Texas.

"Computer program development: section balancing, strain analysis, fault modeling": presented to the Industrial Associates of the Applied Geodynamics Laboratory, Austin, Texas.

John G. Sclater

Citationist for Dan P. McKenzie, recipient of the Arthur L. Day Medal: presented to the Geological Society of America, 1989 annual meeting, St. Louis, Missouri.

Rainer K. Senger

"Hydrodynamics of gravity-driven flow systems in sedimentary basins: examples of the Palo Duro Basin, Texas": presented to The University of Texas at Austin, Department of Geological Sciences, Technical Sessions, Austin, Texas.

"A numerical approach for simulating streamfunctions and equivalent fresh-water heads in variable-density ground water": presented to The University of Texas at Austin, Department of Geological Sciences, Hydrology Seminar, Austin, Texas.

Steven J. Seni

"Texas salt domes: natural resources and aspects affecting waste disposal": presented to a local review committee for a town meeting, Dayton, Texas.

"Salt tectonics and remobilization of salt sheets, northern Gulf of Mexico": presented to Shell Oil Company, New Orleans, Louisiana.

"Salt tectonics in the deep water Gulf of Mexico": presented to the University of New Orleans, Department of Geology, New Orleans, Louisiana.

"Salt tectonics and hydrocarbon exploration on the continental slope, northern Gulf of Mexico": presented to the U.S. Department of the Interior, Minerals Management Service, New Orleans, Louisiana.

"Salt sheet reactivation in the Green Canyon Area": presented to the Industrial Associates of the Applied Geodynamics Laboratory, Austin, Texas.

Noel Tyler

"National potential for oil reserve growth in heterogeneous reservoirs": presented as the keynote address to Exxon Company, USA, Professional Reservoir Management Workshop, Houston, Texas.

"Reservoir heterogeneity and play analysis": presented to the U.S. Department of Energy, Deputy Assistant Secretaries of Fossil Energy, Austin, Texas.

"Opportunities for increased recovery in mature provinces: the Texas experience": presented to the Exxon Innovation Center Workshop on Creativity, Houston, Texas.

"Characterization of heterogeneous reservoirs": presented to the University of Houston, Department of Geology, Houston, Texas.

"Geologically enhanced oil recovery": presented to the Energy Defense Industry Analysis Group, National Defense University Class, Austin, Texas.

"Reservoir models determined from well logs: delineating untapped and bypassed hydrocarbons": presented to the Society of Professional Well Log Analysts, Houston, Texas.

"Reserve growth in mature provinces through improved recovery of mobile oil: the promise of characterization of heterogeneous reservoirs": presented to the U.S. Geological Survey, Office of Marine and Energy Resources, Denver, Colorado.

"Architecture of heterogeneous reservoirs": presented to the Colorado School of Mines, Department of Geology, Golden, Colorado.

Bruno C. Vendeville

"Experiments on basement-controlled faulting in layers with different rheological properties": presented to Leeds University, Deformation Mechanisms, Rheology and Tectonics meeting, Leeds, England.

"Experimental results at the Applied Geodynamics Laboratory in 1989: diapirism and growth faulting": presented to TOTAL (Compagnie Française des Pétroles), Paris, France.

"Experimental modeling of 3-dimensional extension structures": presented to Institut Française du Pétrole, Rueil-Malmaison, France.

"Experimental modeling of syndepositional gravity sliding": presented to The University of Texas at Austin, Institute for Geophysics, Austin, Texas.

"Physical models of normal faulting during extension": presented to Chevron International, Inc., New Orleans, Louisiana.

"Status of modeling normal faults," "Background on physical modeling," "Rollover in listric normal faults," and "Diapiric allochthonous tongues": presented to the Industrial Associates of the Applied Geodynamics Laboratory, Austin, Texas.

E. G. Wermund

"A geological application of GIS": presented to the Texas Natural Resources Information System, Austin, Texas.

"Area geology, rocks, and the soil": presented at the Winedale Spring Symposium, The University of Texas Winedale Historical Center, Winedale, Texas.

"Status of Bureau of Economic Geology research": presented to Texas A&M University, Department of Soil Sciences, College Station, 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 1989:

Walter B. Ayers, Jr.

"Geologic controls on the occurrence and producibility of coalbed methane in north-central San Juan Basin, New Mexico"

Virgil E. Barnes

"Tektite research"

Robert W. Baumgardner, Jr.

"Geomorphology of Hueco Bolson in the vicinity of the low-level radioactive waste site, Hudspeth County, Texas"

L. F. Brown, Jr.

"A sequence-stratigraphic and systems-tract model of the Virgilian and Wolfcampian Series, Eastern Shelf and adjacent Midland Basin, Texas"

Robert J. Finley

"Natural gas reservoir characterization: the Gas Initiative and Secondary Gas Recovery Projects"

R. Stephen Fisher

"Hydrochemistry of ground water beneath a thick unsaturated zone in parts of the Hueco Bolson and Diablo Plateau, Trans-Pecos Texas"

Thomas C. Gustavson

"Salt dissolution: part I, structural controls of salt dissolution and the physiographic development of northwestern Texas and eastern New Mexico"

"Salt dissolution: part II, antitaxial satin spar veins, an indicator of dissolution-induced subsidence in evaporite basins"

"Bolson sediments in the Hueco Bolson, Rio Grande Rift, West Texas"

Susan D. Hovorka

"Porosity development in chert: Three Bar Devonian field, Andrews County, Texas"

Martin P. A. Jackson

"Salt welds: vanishing salt and enigmatic structures"

Lee A. Jirik

"Reservoir heterogeneity in Seeligson field, South Texas: development of recompletion candidates in compartmentalized and bypassed gas zones"

William R. Kaiser

"Fruitland Formation hydrology and producibility of coalbed methane, San Juan Basin, New Mexico and Colorado"

Charles Kerans

"Use of parasequence-scale framework for characterizing reservoir heterogeneity: examples from the San Andres Formation of West Texas and New Mexico"

Dennis R. Kerr

"Fluvial architecture and reservoir heterogeneity in the Oligocene middle Frio of South Texas"

Richard P. Langford

"Depositional environment and reservoir properties of Oligocene Vicksburg Formation gas reservoirs, McAllen Ranch field, Hidalgo County, Texas"

Richard P. Major

"Depositionally and diagenetically controlled reservoir heterogeneity, Jordan field, University Lands, Ector and Crane Counties, Texas"

"Marine diagenesis in magnesian calcite"

Marcus E. Milling

"Geoscience Institute for Oil and Gas Recovery Research: plans and activities for a new initiative"

Robert A. Morton

"Interactions of storms, seawalls, and beaches of the Texas Gulf Coast"

William F. Mullican III

"Regional hydrologic investigations of the saturated zone at the proposed low-level radioactive waste disposal facility in Trans-Pecos Texas"

H. Seay Nance

"Implications of regional correlations: San Andres Formation paleogeography and dolomite distribution"

Jeffrey G. Paine

"Impact of Hurricane Gilbert on beaches of the Texas coast"

Stephen C. Ruppel

"The Siluro-Devonian of West Texas: regional trends in facies and reservoir development"

Bridget R. Scanlon

"Analysis of unsaturated flow related to low-level radioactive waste disposal in the Chihuahuan Desert, West Texas"

Steven J. Seni

"Salt tectonics on the continental slope, Green Canyon Area, northern Gulf of Mexico"

Noel Tyler

"Reservoir architecture and unrecovered mobile oil: systems, paradigms, and promise"

Bruno C. Vendeville

"Scaled tectonic modeling: the basic method and some examples with interacting rock flow and rock faulting"

William A. White

"Marsh aggradation rates determined by artificial-marker horizons, Colorado and Trinity River deltas"

Congressional, Legislative, and Special Testimony

William L. Fisher

Testimony on enhanced oil recovery, S.828: given to the U.S. Senate, Committee on Finance, Subcommittee on Energy and Agricultural Taxation, Washington, D.C.

Testimony on the U.S. resource base and production capabilities for oil and natural gas: given to the U.S. Department of Energy, National Energy Strategy Hearings, Houston, Texas.

H. Scott Hamlin

Expert testimony on the geology and hydrology of Barbers Hill salt dome, Chambers County, Texas: given to the Railroad Commission of Texas, Oil and Gas Division, Austin, Texas.

Charles W. Kreitler

Testimony on the Department of Energy Geopressured-Geothermal Energy Research Program: given to the U.S. House of Representatives, Committee on Science, Space, and Technology, Subcommittee on Energy Research and Development, Washington, D.C.

Marcus E. Milling

Testimony on the role of technology in oil and gas recovery: given to the U.S. Department of Energy, National Energy Strategy Hearings, Houston, Texas.

Robert A. Morton

Expert testimony on wetlands loss in Texas: given to the U.S. House of Representatives, Water Resources Subcommittee, Port Lavaca, Texas.

Noel Tyler

Briefing on the oil reserve base in Texas: given to the Texas Legislature, House Energy Committee, Austin, Texas.

Committee Services, Offices, and Other Professional Responsibilities

Walter B. Ayers, Jr.

Chairman, Field Trip Committee, Energy Minerals Division, American Association of Petroleum Geologists, 1991 annual meeting, Dallas, Texas.

Robert W. Baumgardner, Jr.

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

Don G. Bebout

Chairman, Technical Program Committee, Society of Economic Paleontologists and Mineralogists.

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

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

Leader of field trip, "Lower Cretaceous carbonate facies and depositional environments," Austin Geological Society.

Leader of field trip, "Lower Cretaceous Pipe Creek reef complex," Society of Petroleum Engineers.

Leader of field trip, "Lower Cretaceous facies and depositional environments," Continental Margins Symposium, Minerals Management Service, U.S. Department of the Interior, and Continental Margins Committee, American Association of Petroleum Geologists, Austin, Texas.

Co-Leader of field trip, "Carbonate rock sequences from the Cretaceous of Texas," 28th Session of the International Geological Congress.

Co-Leader of field trip, "Lower Cretaceous shelf carbonates, Central Texas Hill Country," American Association of Petroleum Geologists, 1989 annual meeting.

L. F. Brown, Jr.

Co-Chairman, Application of Seismic Data to Stratigraphic Interpretation Technical Session, American Association of Petroleum Geologists, 1989 aunual meeting.

Carolyn E. Condon

Chairman, Newsletter Committee, Austin Geological Society.

Coordinator, Technical Advisory Panel of the Special Committee on the Edwards Aquifer, Texas State Legislature.

Alan R. Dutton

Chairman, Technical Program Committee, Hydrology Division, Geological Society of America, 1990 annual meeting, Dallas, Texas.

Shirley P. Dutton

Co-Chairman, Siliciclastic Diagenesis II: Influence of Depositional Environment Technical Session, Society of Economic Paleontologists and Mineralogists, American Association of Petroleum Geologists, 1989 annual meeting.

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

Member, Abstract Review Committee for Sedimentary Petrology, Geological Society of America, 1989 annual meeting.

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

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

Member, Technical Program Committee of the Society of Economic Paleontologists and Mineralogists, American Association of Petroleum Geologists, 1989 annual meeting.

Robert J. Finley

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

Chairman, Best of Society of Petroleum Engineers Paper Selection Committee, American Association of Petroleum Geologists.

Chairman, Integrated Approaches to Reservoir Characterization: Best of SPE Technical Session, American Association of Petroleum Geologists, 1989 annual meeting.

Co-Chairman, Development Geology: U.S. Gulf Coast and Permian Basin Technical Session, American Association of Petroleum Geologists, 1989 annual meeting.

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

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

Alternate Representative, Texas Natural Resources Information System Task Force.

William L. Fisher

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

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

Chairman, Nominating Committee, American Association of Petroleum Geologists.

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

Chairman, Committee on U.S. Resources Base, Governmental Affairs Committee, American Association of Petroleum Geologists.

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

Chairman, Technical Advisory Panel, Texas Senate-House Joint Special Committee on Edwards Aquifer.

Chairman, Search Committee, American Geological Institute.

Chairman, Enhanced Recovery Committee, Texas Independent Producers and Royalty Owners.

Co-Chairman, Board on Earth Sciences and Resources, National Academy of Sciences.

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

Vice-President and President-Elect, American Geological Institute.

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

Councilor, Geological Society of America.

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

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

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

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

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

Member, White House Science Council.

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

Member, Advisory Council, Gas Research Institute.

Member, Nominating Committee, Gas Research Institute.

Member, National Petroleum Council.

Member, Agenda Committee, National Petroleum Council.

Member, Natural Gas Supply Committee, American Gas Association.

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

Member, Research Committee, Interstate Mining Compact Commission.

Member, Research Committee, Interstate Oil Compact Commission.

Member, Texas Scientific Advisory Council.

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

Member, Governing Board, American Geological Institute.

Member, Audit Committee, American Geological Institute.

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

Member, Advisory Council, American Association of Petroleum Geologists.

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

Member, National Geological Mapping Implementation Committee, Association of American State Geologists.

Member, Nuclear Waste Committee, Association of American State Geologists.

Member, Advisory Board, Geology Associates, The University of Kansas.

Member, Geology Advisory Group, Southern Illinois University.

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

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

Member, Artificial Reef Advisory Committee, Texas Department of Parks and Wildlife.

Charter Member, Governor's Energy Council (Texas).

L. Edwin Garner

President, Austin Geological Society.

Member, Geotechnical Advisory Panel, Superconducting Super Collider Project.

Chester M. Garrett, Jr.

Chairman, Austin Geological Society delegation to the House of Delegates, American Association of Petroleum Geologists.

Member, Research Committee, American Association of Petroleum Geologists.

Member, Grants-In-Aid Subcommittee, American Association of Petroleum Geologists.

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

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

Judge, Best Paper Award and A. I. Levorsen Memorial Award, Gulf Coast Association of Geological Societies, 1989 annual meeting.

Thomas C. Gustavson

Co-Leader of field trip, "Aspects of the Quaternary stratigraphy and geomorphology of Central Texas," Friends of the Pleistocene, 1989 annual meeting.

Christopher D. Henry

Leader of field trip, "Mid-Tertiary silicic, alkalic magmatism of Trans-Pecos Texas: rheomorphic tuffs and extensive silicic lavas," International Association of Volcanism and Chemistry of the Earth's Interior, General Assembly, Santa Fe, New Mexico.

Organizer and Chairman, symposium on "High-Temperature Pyroclastic and Lava Eruptions," International Association of Volcanism and Chemistry of the Earth's Interior, General Assembly, Santa Fe, New Mexico.

Member, Atlas Editorial Board, Rio Grande Rift Consortium.

Tucker F. Hentz

Co-Leader of field trip, "Permo-Carboniferous vertebrate paleontology, lithostratigraphy, and depositional environments of North-Central Texas," Society of Vertebrate Paleontologists, 1989 annual meeting.

Claude R. Hocott

Member, Committee on Residual Oil Saturation, Interstate Oil Compact Commission.

Member, Research Committee, Interstate Oil Compact Commission.

Susan D. Hovorka

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

Martin P. A. Jackson

Associate Editor, Geological Society of America *Bulletin*.

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

Co-Chairman, U.S. Gulf Coast: Structure and Salt Tectonics Technical Session, American Association of Petroleum Geologists, 1989 annual meeting.

Co-Chairman, Mechanics: Internal Characteristics and Movement Technical Session, Society of Economic Paleontologists and Mineralogists, Gulf Coast Section, Tenth Annual Research Conference.

Member, International Union of Geological Sciences Commission on Tectonics.

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

Charles Kerans

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

Co-Chairman, Carbonate Diagenesis Technical Session, Society of Economic Paleontologists and Mineralogists, American Association of Petroleum Geologists, 1989 annual meeting.

Member, Technical Program Committee, Society of Economic Paleontologists and Mineralogists, American Association of Petroleum Geologists, 1989 annual meeting.

Dennis R. Kerr

Co-Chairman, Siliciclastic Depositional Systems II Technical Session, Society of Economic Paleontologists and Mineralogists, American Association of Petroleum Geologists, 1989 annual meeting.

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

Charles W. Kreitler

Chairman, O. E. Meinzer Award Committee, Geological Society of America.

Member, National Drinking Water Advisory Council, U.S. Environmental Protection Agency.

Member, Technical Advisory Panel, Special Committee on the Edwards Aquifer, Texas Legislature.

Stephen E. Laubach

Chairman, Structural Geology and Tectonics Technical Session, Geological Society of America, South-Central Section, 1989 annual meeting.

F. Jerry Lucia

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

Co-Chairman, Carbonate Diagenesis Technical Session, Society of Economic Paleontologists and Mineralogists, American Association of Petroleum Geologists, 1989 annual meeting.

Leader of field trip, "The lower Paleozoic of West Texas and southern New Mexico: modern exploration concepts," Society of Economic Paleontologists and Mineralogists, Permian Basin Section, Field Seminar.

Richard P. Major

Delegate, Resolutions Committee, House of Delegates, American Association of Petroleum Geologists.

Chairman, Technical Program Committee, Austin Geological Society.

Co-Chairman, Geochemistry, Diagenesis, and Source Rocks Technical Session, Society of Economic Paleontologists and Mineralogists, American Association of Petroleum Geologists, 1989 annual meeting.

Co-Chairman, Rock/Water Interactions in Carbonate Rocks and Sediments I Technical Session, Geological Society of America, 1989 annual meeting.

Treasurer, Austin Geological Society.

Judge, Carbonate Facies and Depositional Systems Technical Session, Society of Economic Paleontologists and Mineralogists, American Association of Petroleum Geologists, 1989 annual meeting.

Member, Technical Program Committee, Society of Economic Paleontologists and Mineralogists, American Association of Petroleum Geologists, 1989 annual meeting.

Amanda R. Masterson

Chairperson, Best Paper Award Committee, Geoscience Information Society.

Member, Publications Committee, Association of Earth Science Editors.

Marcus E. Milling

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

Councilor, Geological Society of America.

Chairman, Human Resources Advisory Committee, American Geological Institute.

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

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

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

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

Member, Research Committee, Interstate Oil Compact Commission.

Co-Chair, The Geoscientist's Role in Enhanced Recovery, American Association of Petroleum Geologists, Rocky Mountain sectional meeting.

Convener, Development Geology Poster Session, American Association of Petroleum Geologists, 1990 annual meeting.

Robert A. Morton

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

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

Member, Coastal Erosion Task Force, U.S. Environmental Protection Agency Gulf of Mexico Program.

Invited participant, panel discussion, Corpus Christi City Council.

Douglas C. Ratcliff

Chairman, Field Trip Committee, Austin Geological Society.

Stephen C. Ruppel

Co-Chairman, Carbonate Facies and Depositional Systems Technical Session, Society of Economic Paleontologists and Mineralogists, American Association of Petroleum Geologists, 1989 annual meeting.

Member, Technical Program Committee, Society of Economic Paleontologists and Mineralogists, American Association of Petroleum Geologists, 1989 annual meeting.

Bridget R. Scanlon

Project Leader affiliated with the Nuclear Regulatory Commission, International Validation of Flow and Transport Committee.

John G. Sclater

Chairman, Ocean Studies Board, National Academy of Sciences/National Research Council.

Allan R. Standen

Member, Core and Sample Committee, American Association of Petroleum Geologists.

Noel Tyler

Co-Chairman, Three-Dimensional Architecture of Clastic Sediments I Technical Session, Society of Economic Paleontologists and Mineralogists, American Association of Petroleum Geologists, 1989 annual meeting.

Co-Chairman, Three-Dimensional Architecture of Clastic Sediments II Technical Session, Society of Economic Paleontologists and Mineralogists, American Association of Petroleum Geologists, 1989 annual meeting.

Co-Chairman, Reservoir Characterization Subcommittee, Geoscience Institute for Oil and Gas Recovery Research.

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

Member, Technical Study Committee, Geoscience Institute for Oil and Gas Recovery Research.

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

Edmund G. Wermund

Chairman, Loss of Physical Habitat and Living Resources Subcommittee, Scientific/Technical Advisory Committee, Galveston Bay National Estuary Program.

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

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

Member, Texas Mapping Advisory Committee.

William A. White

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

Sally G. Zinke

President, Denver Geophysical Society.

Chairman, Seismic Interpretation I: Amplitude Versus Offset I Technical Session, Society of Exploration Geophysicists, 1989 International Meeting and Exposition.

Judge, Seismic Interpretation I: Amplitude Versus Offset I Technical Session, Society of Exploration Geophysicists, 1989 International Meeting and Exposition.

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

Member, Continuing Education Committee, Society of Exploration Geophysicists.

Member, Annual Midwest Regional Convention Committee, Society of Exploration Geophysicists.

Member, Society of Exploration Geophysicists Council.

University Teaching/ Continuing Education

Walter B. Ayers, Jr.

"Definition of the coalbed methane reservoir": short course presented to the Gas Research Institute, Coalbed Methane Workshop, Technical Session I, Part III, Pittsburgh, Pennsylvania.

"Hydrologic indicators of gas producibility": short course presented to the Gas Research Institute, Coalbed Methane Workshop, Technical Session I, Part IV, Pittsburgh, Pennsylvania, and Dallas, Texas.

Robert J. Finley and Noel Tyler

"Characterization of heterogeneous reservoirs": short course presented to the Universidad Federal de Ouro Preto, Escola de Minas, Ouro Preto, Brazil.

William L. Fisher and Noel Tyler

"Petroleum geology: exploration and redevelopment" (Geology 391): 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 basin analysis" (Geology 391): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

"Recognition of fluvial depositional systems and their resource potential": short course presented to the American Association of Petroleum Geologists, 1989 annual meeting, San Antonio, Texas.

Lecturer in the Lower Wilcox Core Workshop: short course presented to the American Association of Petroleum Geologists, 1989 annual meeting, San Antonio, Texas.

"Analysis of sedimentary basins": short course presented to the Universidad Federal de Ouro Preto, Escola de Minas, Ouro Preto, Brazil.

"Genetic stratigraphic sequences in clastic basins: a recognition and interpretation workshop": short course presented to The University of Texas at Austin, Bureau of Economic Geology, Austin, Texas.

Claude R. Hocott

"Fundamentals of petroleum engineering" (PEN 320): The University of Texas at Austin, Department of Petroleum Engineering, Austin, Texas.

Charles Kerans

"Styles of reservoir heterogeneity in selected Ellenburger reservoirs, Permian Basin, West Texas": short course presented to the Permian Basin Graduate Center, Midland, Texas.

Charles Kerans, F. Jerry Lucia, and Richard P. Major

"Development geology: strategies for recovery of oil remaining in existing reservoirs": short course presented to the American Association of Petroleum Geologists, Student Chapter, 1989 annual meeting, San Antonio, Texas.

Stephen E. Laubach

"Techniques of comprehensive evaluation and completion of tight gas sands": co-lecturer of short course presented to the Society of Petroleum Engineers Gas Technology Symposium, Dallas, Texas.

Robert A. Morton

"Coastal land loss": co-lecturer of short course presented to the 28th Session of the International Geological Congress, Washington, D.C.

Bridget R. Scanlon

"Unsaturated-flow studies related to low-level radioactive waste disposal": short course sponsored by the American Nuclear Society and presented to the University of Nevada, Las Vegas, Nevada.

John G. Sclater

"Geodynamics: plate tectonics, marine geology, and geophysics" (Geology 358D): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

"Geology for engineers" (Geology 312K): 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 million in purchases and subcontracts, and handles publication sales in excess of $100,000 per year. Wanda L. LaPlante, Executive Assistant, supervises this section.

Cartography

The Bureau's Cartographic section maintains an excellent record of producing high-quality, full-color maps. This section also fulfills the Bureau's drafting needs for black-and-white plates, text figures, slides, posters, and display materials and provides in-house photographic services. Under the supervision of Richard L. Dillon, Chief Cartographer, this section produced 9 full-color maps, 67 black-and-white plates, 1,500 text figures, and 1,200 visual aids during the year.

Operating with the fewest staff members since 1983, this section produced more items than in previous years due to computerization of some drawing functions. Two IBM-PC-based graphics systems are used in producing slides, and two Macintosh II computers are used to produce some posters and text figures. In 1989 approximately 75 percent of all slides and 30 percent of the text figures were computer generated.

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. The section supports programming and data base applications on Bureau computers (including a VAX cluster, more than 35 networked personal computers, and 20 high-quality output devices), the University's Cyber and IBM computers, and the Center for High Performance Computing's VAX and Cray systems.

In 1989, under the supervision of Elizabeth D. Orr, Manager of this section, the Computer Resources staff added a VAXstation 3100 to the VAX cluster, and a Silicon Graphics Iris workstation to the network. Both workstations will be used for three-dimensional geologic modeling and mapping. A new 386 PC-based workstation was purchased for geologic mapping, as well as for future applications in geographic information systems, geophysical data analysis, and semi-automatic log digitizing. The staff completed development of a computerized administrative accounting system, several large oil and gas related data base systems, and several Cray programs for simulation of fluid-flow pathways in petroleum reservoirs and aquifers. The staff also completed designs for a new automated inventory and tracking system for the Core Research Center,, a charge-back system for personal computer use, and a publication sales and inventory system.

Publications

The Publications section provides support to the scientific, administrative, and other support staffs in processing manuscripts and designing publications. This staff of proofreaders, editors, typographers, and designers handles proofreading, editing, word processing, typesetting, and desktop publishing, as well as design and layout of all Bureau publications. The staff is also responsible for producing contract reports submitted to funding agencies and papers and abstracts submitted to professional journals. Susann Doenges, Editor-in-Charge, supervises the section.

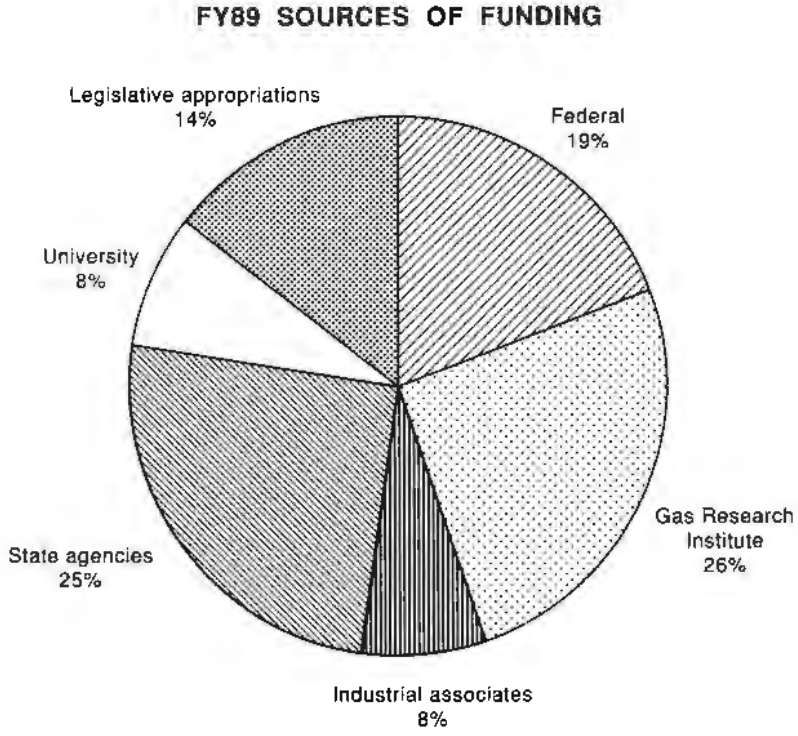
During 1989 the Bureau issued 19 new publications, 3 of which also served as final contract reports, and 21 independent contract reports. The word processing and typesetting areas handled more than 18,000 and almost 5,000 pages, respectively. In addition, more than 23,000 pages of text were proofread, and more than 5,500 pages were edited during the year.

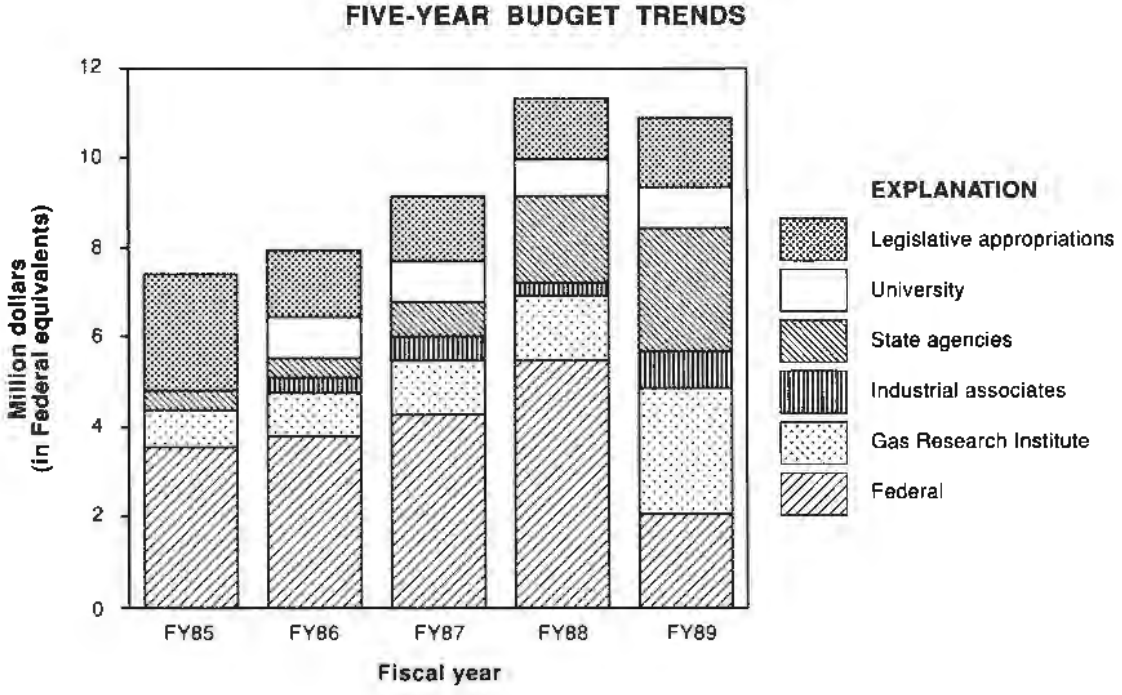
Quality Assurance

The Quality Assurance Group, supervised by Carolyn Condon, develops and maintains the Bureau's Quality Assurance Program. The group directly supports scientific research and administration activities by interpreting regulatory and contractual requirements and preparing and issuing Quality Assurance Procedures to ensure compliance with the requirements. The staff consists of trained Lead Auditors who, in addition to preparing documents, perform audits to determine effective implementation of the Quality Assurance Program.

During 1989, the Quality Assurance Group was responsible for the preparation and issuance of six Quality Assurance Procedures associated with low-level radioactive waste site investigation studies. Twenty Specific Work Instructions were also issued. Additionally, the Quality Assurance Group conducted 10 audits of Bureau and vendor activities and managed the Quality Assurance Records Center, where Quality Assurance Records are stored for future access by or turnover to contracting agencies.

Sources of Funding and Budget Trends





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