ANNUAL REPORT 1987

Bureau of Economic Geology

W. L. Fisher, Director

The University of Texas at Austin

Austin, Texas 78713

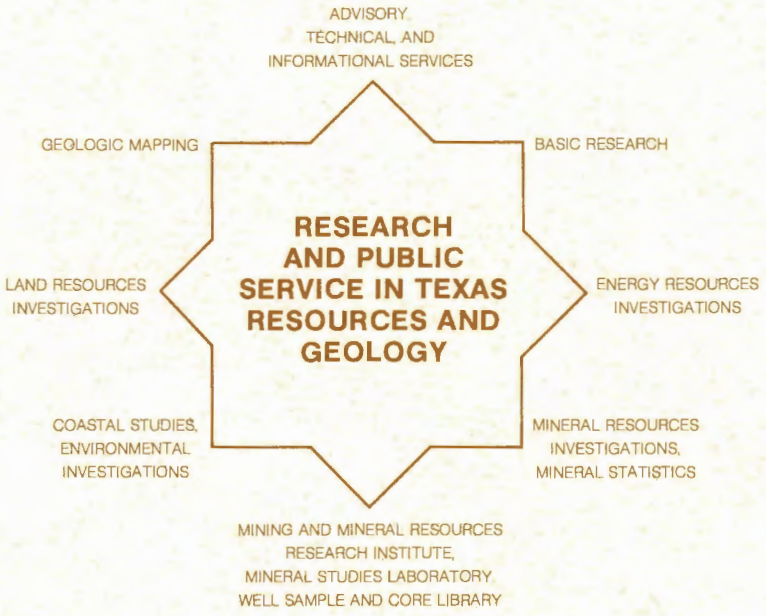
The Bureau of Economic Geology, established in 1909 as the successor to the Texas Geological Survey and the Texas Mineral Survey, is a research entity of The University of Texas at Austin. It also functions as the State Geological Survey, a quasi-State agency, and the Bureau Director represents Texas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

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

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

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

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



On the cover: Large molds of the bivalve *Trigonia* and high-spired gastropods in a Lower Cretaceous carbonate grainstone matrix. This widely used building stone, from the quarries at Cedar Park northwest of Austin, forms the facade of the main entrance to the Bureau's Research and Administration Building. It is generally interpreted to have been deposited about 100 million years ago in a shoreface environment associated with an ooid-bar complex.

Cover design by Margaret L. Evans. Photograph by James A. Morgan.

Annual Report

1987

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Research

Research in 1987 reflects the Bureau of Economic Geology's commitment to assess the potential for and assist in the effective development of Texas' natural resources (energy, minerals, land, and water) and in the ensurance of safe disposal of resulting waste products. In addition to these efforts, the Bureau maintained a variety of fundamental geologic investigations.

Exploration targets for oil and gas continue to move farther offshore and into deeper waters. Industry's interest in these potential targets is evidenced by its support of a Bureau program to investigate the potential of the Northwest Gulf of Mexico Continental Shelf. Bureau studies of downdip oil and gas plays that underlie State submerged lands were supported by Texas government.

Investigation of ways to increase production from older, mature hydrocarbon reservoirs continued. Research to further quantify recoverable mobile oil focused on carbonate reservoirs in the Permian Basin of Texas, which in the past decade have exhibited the greatest oil reserve-growth potential in the state and possibly in the nation. Developments were made in relating carbonate rock fabrics, geologic concepts, and engineering calculations to devise stochastic methods for predicting reservoir potential in computer models that numerically simulate depleting reservoirs. Bureau scientists in the industry-funded Reservoir Characterization Research Laboratory concluded that the highest cumulative production from Spraberry reservoir compartments is located along the predominantly channelized depositional axes in the Midland Basin.

A new program was initiated to study the interaction of geologic and hydrologic factors, including sand-body geometry, coal seam continuity, permeability, and ground-water flow, that determine the availability and producibility of coalbed methane. In another new study, Bureau scientists are using criteria from previous research on declining petroleum reservoirs to assess gas reservoirs for improved recovery technology.

A 5-year program investigating low-permeability gas sandstone reservoirs led in 1987 to locating, drilling, and evaluating an experimental well in the Travis Peak Formation of East Texas. Core studies revealed critical information on the nature of porosity and permeability in tight gas reservoirs. A better understanding of factors controlling fracture distribution and state of stress in tight gas sandstones will help improve completion techniques in these marginal hydrocarbon reservoirs.

Preparation of the "Atlas of Major Texas Gas Reservoirs" accelerated in 1987. The atlas will serve as a base for future studies of gas-reserve growth in specific fields and plays and will initiate detailed field and subregional geologic analyses of gas-reservoir heterogeneity. Researchers grouped 2,000 reservoirs into 84 geologically distinct gas plays, each based on reservoir genesis, formation, lithology, trapping mechanism, petrophysical properties, and geographic location. The largest number of plays was delineated in the Gulf Coast Province (35 in Railroad Commission of Texas [RRC] Districts 1 through 4) and in West Texas (22 in RRC Districts 7C, 8, and 8A). The atlas is scheduled to be published in late 1988.

Research conducted for the U.S. Department of Energy on the potential for a high-level waste repository in the Texas Panhandle continued in 1987. Studies concentrated on site characterization analyses. A Bureau-sponsored symposium and field trip on the Ogallala and Blackwater Draw Formations, which emphasized stratigraphy, pedology, paleoclimate, and formation of playa lake basins, attracted researchers from throughout the United States. In 1987, the Texas Low-Level Radioactive Waste Disposal Authority asked the Bureau to investigate another potential Hudspeth County site, where principal concerns were depth to water table, permeability of host sediments and rocks, and rates and directions of ground-water flow. This program has permitted a better understanding of the hydrology of a large part of arid West Texas, and research indicates that major water resources may exist beneath the Diablo Plateau. Related research investigated the hydrogeology of the Edwards aquifer near Georgetown and causes for salinization in the San Angelo area.

Two Bureau programs have started to look at the problem of chemical waste disposal. The major method of disposal of hazardous chemical waste in Texas is by deep-well injection. Research sponsored by the U.S. Environmental Protection Agency (EPA) has focused on mapping potentiometric surfaces and analyzing water chemistry to characterize the regional hydrogeology of these saline formations. A second program, also sponsored by EPA, has begun evaluating whether these hazardous wastes degrade to harmless chemicals in the deep subsurface.

Bureau mineral resource investigations covered a variety of commodities throughout the state. A project to assess the potential for sulfur resources on State-owned lands in Trans-Pecos Texas combined data from exploration drill records, reports available in the literature and in public files, and aerial photographs to produce resource potential maps showing areas considered to be most favorable for sulfur-ore formation. Studies of igneous petrogenesis and ore deposition focused on recently discovered high-grade beryllium deposits and related low-grade, large-tonnage resources of rare earth elements, niobium, and thorium near Sierra Blanca, Texas, and somewhat similar rocks in the Christmas Mountains area. Research on regional

tectonics has provided explanations for the abundance and size of certain types of precious metal veins in Texas, relative to other portions of western North America. A forthcoming report on the Texas cement industry and cement resources will add to the Bureau's publications on industrial minerals. New industrial mineral projects initiated in 1987 will investigate the dimension stone and aggregate industries in Texas.

Publication of the Wichita Falls-Lawton Sheet in 1987 completed the Bureau's *Geologic Atlas of Texas*. The entire state is now mapped at a scale of 1:250,000. Progress is being made on preparing complementary Bouguer gravity and magnetic maps, a 1:500,000-scale geologic map of Texas, and a 1:750,000-scale tectonic map of Texas. A detailed mapping project in the Davis Mountains was initiated to resolve controversies regarding the origin of large-volume silicic volcanic rocks.

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

Energy Resources Investigations

Petroleum

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

Robert A. Morton, project director; W. B. Ayers, Jr., and Lee A. Jirik; assisted by Nancy Banta, Richard Sams, and Robert Single

This long-term industry-sponsored research program is focused on regional genetic stratigraphy, structure, and energy resources of the Texas portion of the continental shelf and upper slope. The primary data base, which has been gathered during the past 5 years, includes more than 2,000 conventional well logs, numerous paleontologic reports, seismic lines selected from regional grids, scout tickets, and production records. In 1985, an industrial associates group was organized to maintain the research effort and to increase the exchange of information with potential users. Companies supporting the effort in 1987 were Consolidated Natural Gas, Louisiana Land and Exploration, Mobil, Pennzoil, Standard Oil, Tenneco, Texaco, and Total Minatome.

In 1987, correlation and quantitative mapping of Plio-Pleistocene stratigraphic units 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.

A deep-water (slope) phase of the project was initiated in 1987 involving correlating logs in the northern East Breaks and western Garden Banks areas and integrating the lithostratigraphic and biostratigraphic correlations into a regional grid of seismic lines. Scheduled for 1988 are a series of maps and cross sections for the slope that will complement those prepared for the adjacent shelf.

Studies Related to Continental Margins, Year 3

Steven J. Seni, principal investigatar; H. Scott Hamlin

Under Douglas C. Ratcliff's direction, the Bureau coordinates the multidisciplinary Continental Margins program sponsored by 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. Geological surveys of coastal states receive funds from MMS to conduct studies relevant to the needs of the individual states and of the Federal offshore program.

In 1987 the Bureau hosted the First Symposium on Studies Related to Continental Margins. During the symposium, representatives from MMS and participating coastal states summarized activities of the first 2 years of the program. The Bureau's research during year 3 of the program involved characterization of distal Frio reservoirs in offshore State waters. Several areas were outlined where exploration for Frio gas in new fields is economically feasible out into Federal waters.

Characteristics of Distal Frio Reservoirs, Corpus Christi Area

Robert A. Morton, principal investigator

During year 4 of the Continental Margins program, fields in the Corpus Christi Bay area producing from distal Frio sandstones were selected for detailed investigation of reservoir characteristics. Several hundred feet of cores from different reservoirs in three wells were described, and plots were made of grain size, sedimentary structures, and pore properties (porosity and permeability). This phase of investigation revealed that (1) sandstones were deposited in distal shoreface and shelf environments and (2) permeability values are highest where sedimentary structures (foresets, ripple laminations) are preserved and poorest where bioturbation completely destroys primary structures. Point counts of thin sections from one well provided information about sandstone composition and importance of secondary porosity in improving reservoir quality of deep overpressured sediments. Sedimentological, petrographic, and pore property data were combined with log facies maps to identify intrawell heterogeneities that are manifested as different hydrologic units within a reservoir and interwell heterogeneities that appear as zones of higher and lower permeability aligned parallel to depositional strike. Maps depicting these interwell patterns are similar to those of the modern shelf that illustrate textural changes in bottom sediments after passage of an intense storm.

Petroleum Resource Assessment of State-Owned Lands

Steven J. Seni and H. Scott Hamlin

The General Land Office funded a 2-year program to assess petroleum resources along the Texas coast, including all normally submerged lands extending off-

shore to the 3-league (10-mi) line. This program was completed in August 1987. A final contract report was produced on the petroleum resources of the lower Miocene and distal Frio depositional sequences. Large-scale maps (1 inch = 16,000 ft) and computerized data bases of well logs, production on State lands, and production from selected reservoirs were also delivered.

Most production from State lands is from lower Miocene and Frio reservoirs. Annual oil and gas production from these reservoirs has been declining. Differences in exploration maturity, trapping mechanisms, and depositional and reservoir architecture indicate that the Frio and lower Miocene each require individual strategies to enhance petroleum potential.

Most Frio production from State submerged lands is from large mature oil and associated gas fields in Texas bays. In the large mature bay fields, major Frio reservoir sandstones are stacked over broad anticlines. Three-dimensional architecture of the sandstones is commonly complex, affording many targets for infill drilling and reservoir extension. Three-dimensional reconstruction of reservoir architecture using geophysical and well data would target untapped areas of reservoirs containing trapped and bypassed oil.

New fields extending downdip limits of Frio production have been established since the late 1970's in offshore State waters near the State-Federal boundary. These highly productive new gas fields are concentrated downdip from productive onshore areas of Corpus Christi-Copano and Galveston Bays and are characterized by relatively few and typically thin sandstone reservoirs in growth-faulted rollover anticlines. Promise of significant additional offshore Frio production is tempered by the limited extent of reservoir-quality sandstones at currently productive depths.

Exploration is active for lower Miocene gas and gas-condensate reservoirs in complex continental margin settings dominated by growth faults. Fault-controlled traps include listric normal faults, growth-faulted rollover anticlines, fault-sealed dip-reversed fault blocks, and antithetic fault blocks. Combination stratigraphic-structural traps in barrier-bar sandstones are locally significant in Matagorda Area offshore, Espiritu Santo Bay, and Matagorda Bay. Just as with the Frio, additional reserves in the lower Miocene could be obtained by more efficient recovery of hydrocarbons from known fields.

To maximize recovery of hydrocarbons from State submerged lands, recovery of hydrocarbons from known reservoirs must be improved and small and moderate-sized fields must be aggressively sought. Historical high productivity of Frio reservoirs in State bay and lagoonal waters, and relative immaturity of distal Frio and lower Miocene trends in State offshore waters, are favorable aspects that suggest that the reservoirs could be further exploited with fresh reexploration insights and secondary recovery techniques.

Geological Characterization of Reservoirs on University Lands

Noel Tyler, project director; Don G. Bebout, Graham E. Fogg, Chester M. Garrett, Jr., Edgar H. Guevara, Claude R. Hocott, Mark Holtz, Charles Kerans, F. Jerry Lucia, R. P. Major, Prasanta K. Mukhopadhyay, Stephen C. Ruppel, and Gary W. Vander Stoep; assisted by Syrous Bouzari, Harris Cander, Holly Lund, Matthew Parsley, James Reistroffer, John Tenison, Timothy Walter, and John Worrell

The University of Texas System has funded the University Lands Reservoir Characterization project for the past 3 years to conduct research in reservoir geology, reservoir engineering, petrophysics, and computer simulation and modeling in fields located on University Lands in the Permian Basin. The objective of this project is to provide University Lands operators with information developed in integrated multi-disciplinary studies that will enable improved hydrocarbon recovery through modification and extension of existing field development programs. Although 1.2 billion barrels of oil have been produced from reservoirs on University Lands, it is estimated that an additional 1.5 billion barrels of mobile oil remain in these heterogeneous reservoirs. Remaining mobile oil is the target for extended conventional recovery methods.

During 1987, fields in San Andres/Grayburg (Dune, Emma, Farmer, Jordan, Penwell, and Taylor-Link), Spraberry (Benedum), Silurian-Devonian (Three Bar), and Ellenburger (Emma) formations were studied.

San Andres/Grayburg Reservoirs

Geological and engineering studies of the Dune field (Crane County, Texas) were completed, and results of this research are recorded in the Bureau's Report of Investigations No. 168, "Characterization of the Grayburg Reservoir, University Lands Dune Field, Crane County, Texas," by D. G. Bebout, F. Jerry Lucia, C. R. Hocott, G. E. Fogg, and G. W. Vander Stoep. This report describes methods and techniques used to characterize in detail carbonate rock types and diagenetic history and the calibration of well log data to low-temperature core analysis to map permeability trends and remaining oil saturations across part of Dune field. The study resulted in the delineation of more than 10 million barrels of unrecovered mobile oil in an area of only 1 mi^2. The oil is trapped within reservoir heterogeneities inherited from original depositional systems and modified by diagenesis during subsequent burial. Much of this oil (9 million barrels) is concentrated in the southeast corner of Section 15 in Dune field and occurs in a single 100-ft-thick reservoir interval that includes a high-permeability grainstone bar facies. Low recovery of hydrocarbons from this zone is a result of limited reservoir contact during primary production and waterflooding because of pronounced lateral heterogeneity and permeability stratification.

R. P. Major

Cased-hole logging operations at Penwell field (University Lands Block 35, Ector County, Texas) sponsored by the Bureau as part of the University Lands project's test of new oil field technology for locating remaining mobile oil in old fields. The rig visible in the distance is drilling a development well at a site geologically located by Bureau researchers. Initial tests indicate it is a producing well.

The approach developed in the Dune field study has been used to identify an additional 24 million barrels of unrecovered mobile oil in an adjacent part of the field. Successful application of this approach suggests that wider use of integrated reservoir characterization methods offers major economic potential in University Lands reservoirs and, by extension, in other mature fields in the Permian Basin.

Computer simulation of fluid flow in the Dune field reservoir has illustrated how and why part of the remaining mobile oil is being bypassed in the waterflooding process. By incorporating fine details of heterogeneity mapped using geologic data and petrophysical measurements, models show that local zones of high-permeability grainstones initially yield oil but later become thief zones through which most of the injected water is cycled. Resulting poor recovery efficiencies indicate that most of the oil remaining in other parts of the reservoir is not contacted by the waterflood. However, simulation of production from infill wells drilled first on 5-acre and then on 2.5-acre spacings shows significant improvements in production. It appears that with 2.5-acre well spacing, up to 90 percent of the remaining mobile oil could be produced.

Characterization of the Emma San Andres reservoir (Andrews County, Texas), including analysis of facies, depositional setting, diagenesis, and reservoir properties, has been completed. It is estimated that the Emma San Andres reservoir contains 15 million barrels of remaining mobile oil. Thus far, most production (85 percent) has come from the upper porosity interval, a skeletal grainstone deposited as migrating carbonate sand shoals; however, this interval is calculated to contain an additional 8 million barrels of remaining mobile oil. The lower porosity interval, which contains lower permeability, shallow-water subtidal fusulinid packstone and wackestone, contains an additional 7 million barrels of mobile oil.

Geologic and engineering studies of the Taylor-Link West San Andres Unit (Pecos County, Texas) are focusing on problems related to the karst-fracture porosity network within the reservoir. Problems related to this high-permeability system, which causes substantial water cycling during waterflood, are being addressed in the field by the Taylor-Link Operating Company and in the lab by the Bureau through core and log analysis. Bureau investigations include integration of core-analysis, log-analysis, and injection data to aid in differentiating matrix and fracture permeability in areas where core data are unavailable, hence allowing mapping of fracture-permeability trends. Knowledge of fracture trends will be used to guide future waterflood efforts and increase recovery efficiency.

The first phase of geologic study of the East Penwell San Andres Unit (Ector County, Texas) has been completed. Production is almost exclusively from porous pellet and skeletal grainstones in which primary interparticle porosity has been preserved. Highest permeability is in sediments associated with tidal channels that trend parallel to depositional and structural dip. The highest concentration of remaining mobile oil in the unit is in tidal channels and associated sediments, and these features are the target for infill development wells. Four infill wells were drilled in 1987 to test a productive horizon a few hundred feet deeper than the main San Andres reservoir. Preliminary test results indicate all four will be excellent producing wells. One of the 1987 infill wells, the Fina East Penwell San Andres Unit No. 905, was cored through both the upper and lower San Andres reservoirs. The Bureau selected this well for a test of the Gamma-Ray Spectroscopy wireline log, which measures formation element data in cased holes. Calibration of this log with core data will determine whether this tool can be effective in interpreting behind-pipe conditions in old producing wells.

Study has begun on two units in Jordan field (Ector and Crane Counties, Texas), which produce oil from a San Andres Formation reservoir. Preliminary examination of cores indicates that much of the reservoir is pellet and skeletal grainstone containing primary interparticle porosity, similar to that of the San Andres reservoir at Penwell field. However, part of the reservoir at Jordan field is also in thick sections of peritidal pisolite packstone containing fenestral and sheet-crack porosity.

A 12-mi^2 area in University Blocks 49 and 50 of the Farmer field has been selected for detailed geological and engineering characterization primarily because of low recovery efficiency (12 percent) and high volume of remaining mobile oil (61 million barrels) recorded on University Lands in this field. Farmer field is still in primary development, and infill drilling is now taking place prior to waterflooding. Early results indicate that the reservoir section comprises a number of thin, upward-fining cycles; porosity and permeability are best developed in the fine-grained grainstone in the middle of each cycle.

Spraberry Reservoirs

Research on Spraberry reservoirs on University Lands focused on organic geochemistry studies. Preliminary geochemical data (total organic carbon, organic petrography, pyrolysis, liquid and gas chromatography, and stable isotopes) indicate occurrence of source rocks within the Spraberry Formation. Geochemical fingerprinting of upper and lower Spraberry oils and source rocks and proximity of mature source rocks to oil reservoirs suggest multiple oil-source intervals in cyclic Wolfcampian-Leonardian strata and short migration pathways between overlapping source and reservoir rocks in the central Spraberry Trend. A manuscript on the relations between reservoir geology and production characteristics in the Spraberry-Benedum waterflood unit of the Spraberry Trend is now being prepared.

Silurian-Devonian Reservoirs

Investigation of Silurian-Devonian reservoirs on University Lands has begun with study of Amoco's Three Bar field. Preliminary analysis of reservoir rocks indicates that reservoir porosity is developed in pervasively silicified intervals within a limestone interpreted to have been deposited under low-energy conditions. Silicified carbonate reservoirs account for a large percentage of Silurian-Devonian production on University Lands.

Ellenburger Reservoirs

The Lower Ordovician Ellenburger Group represents a major reservoir type on University Lands, containing an estimated 1.7 billion barrels of remaining mobile oil in University Lands reservoirs. A combination of regional studies and more detailed study of the Emma reservoir has led to development of a karst geologic model for reservoir stratification.

By using this karst model, it is possible to recognize at least two discrete producing zones in what have previously been considered homogenous fracture-pore systems. Two main producing zones appear to represent cave-roof and lower (floor) collapse-breccia settings, and they are separated by a relatively impermeable siliciclastic-rich section of cave-fill sediment. The multiple-pay karst model may open up a wide variety of opportunities for deepening and recompleting older Ellenburger wells, where quite commonly only the upper (cave-roof) reservoir is produced.

Related Research

Significant advances have been made in developing methods and techniques for improving characterization of carbonate reservoirs on University Lands. Developments in relating rock fabrics, geologic concepts, and engineering calculations are described in the Bureau's Geological Circular 87-5, "Rock Fabric, Permeability, and Log Relationships in an Upward-Shoaling, Vuggy Carbonate Sequence," by F. Jerry Lucia and Robert D. Conti. Further development of stochastic methods of predicting spatial distribution of porosity, permeability, and oil saturation allows effective integration of geologic data with engineering data in computer models for numerical simulation of reservoirs.

Reservoir Characterization Research Laboratory

Noel Tyler, project director; Edgar H. Guevara, George R. Coates, Prasanta K. Mukhopadhyay, and Michael P. Roberts; assisted by J. Crispin Gholston, John Farrelly, Roger L. Graham, and James Reistroffer

The Reservoir Characterization Research Laboratory (RCRL) is an industry-sponsored, interdisciplinary research program funded by industry through subscriptions. This project is open to organizations interested in taking part in investigations on the geological characterization of heterogeneous petroleum reservoirs and the relations between production characteristics, oil recovery, and reservoir geology. Research conducted in the RCRL benefits from close collaboration between petroleum companies managing reservoirs and researchers conducting studies at the Bureau. In addition to economic support, sponsors generally provide core and production data; reviews are held on a regular basis to transmit research progress, results, and applications.

Using previous studies (by Tyler and Gholston, "Heterogeneous Deep-Sea Fan Reservoirs, Shackelford and Preston Waterflood Units, Spraberry Trend, West Texas," and by Guevara, "Geological Characterization of Permian Submarine-Fan Reservoirs of the Driver Waterflood Unit, Spraberry Trend, Midland Basin, Texas," both to be published in the Bureau's Report of Investigations series) as a basis for further research, the RCRL continued investigations on the geology, hydrocarbon occurrence, and production characteristics of oil reservoirs of the Spraberry Formation (Lower Permian) in the Midland Basin of West Texas. A contract report summarizing studies conducted during 1986–87, "Geological Characterization and Reserve Growth Potential of Spraberry Reservoirs in the Midland Basin, West Texas," was issued to sponsoring companies (ARCO, Exxon, Mobil, Standard Oil, and Texaco). This report highlights opportunities for additional oil recovery through geologically targeted reexploration and extended development.

Spraberry reservoirs are naturally fractured, very fine grained sandstones and siltstones generally occurring in the upper part of submarine-fan deposits of the upper and lower Spraberry. Cores, reservoir pressure data, and suites of open- and cased-hole logs obtained from two wells newly drilled in the central Spraberry Trend locally permitted petrophysical

determinations, formation evaluation, fracture identification, and recognition of untapped Spraberry reservoir compartments. Cross sections and structure, thickness, and log-facies maps of stratigraphic intervals containing these reservoirs were constructed basinwide. Areal distribution of porosity in the main reservoirs in an ununitized area of the central Spraberry Trend east of the Preston/Shackelford and north of the Driver waterflood units was quantified using "old" gamma-ray-neutron logs. Similarly, source-rock potential of Spraberry shales was determined using core samples.

Comparison of geological and production data indicates that lithofacies architecture strongly controls hydrocarbon distribution and recovery in Spraberry reservoirs. Stratigraphically controlled reservoir heterogeneity results in multilayered and laterally compartmentalized oil accumulations. Isolith and log-facies maps display meandering to braided, dip-elongate belts of greater total thickness of sandstone and siltstone that represent axes of predominantly channelized deposition. Wells having the highest cumulative oil production generally occur along these depositional axes.

Investigations on oil reservoirs of the Lower Permian Dean Sandstone of the Midland Basin were initiated in November 1987 with objectives similar to those of the Spraberry study. ARCO, Mobil, Standard Oil, and Texaco are sponsors of this research.

A Geologic-Based Estimate of Oil Reserve Growth in Texas

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

Cost-effective contributions to oil reserve growth in maturely explored petroleum provinces in Texas can be made by application of strategically located infill wells in existing fields. In 1985, Texas added 916 million barrels of oil reserves as opposed to 837 million barrels of production; almost all of these reserves were by reserve growth rather than by new-field discoveries.

The resource base of unrecovered mobile oil in Texas is estimated to be 35 billion barrels. A joint study by the Bureau and IFC-Lewin, a private research organization, to further quantify recoverable mobile oil in specific plays in Texas began in February 1987. This study has initially focused on carbonate reservoirs in the Permian Basin of Texas because this region has shown the greatest oil reserve-growth potential in the state, and possibly in the nation. The Bureau has selected representative reservoirs from the San Andres/Grayburg South Central Basin Platform and Eastern Shelf Permian Carbonate plays in the Permian Basin as well as from the Frio Barrier-Strandplain play in the Gulf Coast Basin for reserve-growth analysis in several geologic settings.

The Grayburg carbonate reservoir in Dune field (South Central Basin Platform) was initially targeted for oil reserve-growth analysis because the geological and reservoir engineering studies had already been conducted for the Bureau's University Lands project. This project identified an additional 10.2 million barrels of remaining mobile oil in 1 mi^2 of Section 15 in Dune field. This oil will be most effectively contacted through a program of geologically based infill wells. Most of this oil is in multiple, stacked lenticular crinoidal grainstone bars that pinch out laterally into relatively nonporous packstones and wackestones. Because of complex vertical and horizontal distribution of reservoir facies in Section 15, wells drilled at regular spacing and at preset depths do not contact all grainstone bars; most of the bars are within northwest-southeast-trending belts that subdivide Section 15 into bands of contrasting productivity and reservoir quality. To tap remaining mobile oil trapped in these lenticular, areally limited reservoirs, infill wells must be strategically located to accommodate the complex facies geometry.

Functions describing theoretical and floodable continuous pay were developed for Grayburg reservoirs in Section 15. These pay-continuity functions relate continuity of pay zones to horizontal distance between existing wells. Pay-continuity values were derived from statistical analysis of permeable zones illustrated on five stratigraphic cross sections that intersect two areas of contrasting reservoir quality. Pay-continuity functions for each of these two areas have been developed and will later form the basis of oil reserve-growth potential.

The Bureau and IFC-Lewin are currently preparing a report for the U.S. Department of Energy that provides details on strategic infill locations in Section 15 and in Dune field at large. A detailed economic analysis is being made to establish amounts of hydrocarbons recoverable at various oil prices. Results are being extrapolated to the play level; preliminary results indicate that nearly 1.2 billion barrels of incremental oil is potentially recoverable from geologically based infill-well development in the South Central Basin Platform play.

Gas

Geological Investigations of Low-Permeability Gas Sandstone Reservoirs

Shirley P. Dutton and Robert J. Finley, project directors; Robert W. Baumgardner, Jr., Michael A. Fracasso, Karen L. Herrington, Stephen E. Laubach, and Robert S. Tye; assisted by Aimee E. Beveridge, Thomas E. Hoak, Karen J. Meador, James K. Miller, and Richard E. Paige

Since 1982, the Gas Research Institute (GRI) has supported geological investigations designed to develop knowledge necessary to produce low-permeability, gas-bearing sandstone efficiently. As part of that program, the Bureau has been conducting research on the Lower Cretaceous Travis Peak (Hosston) Formation, a low-

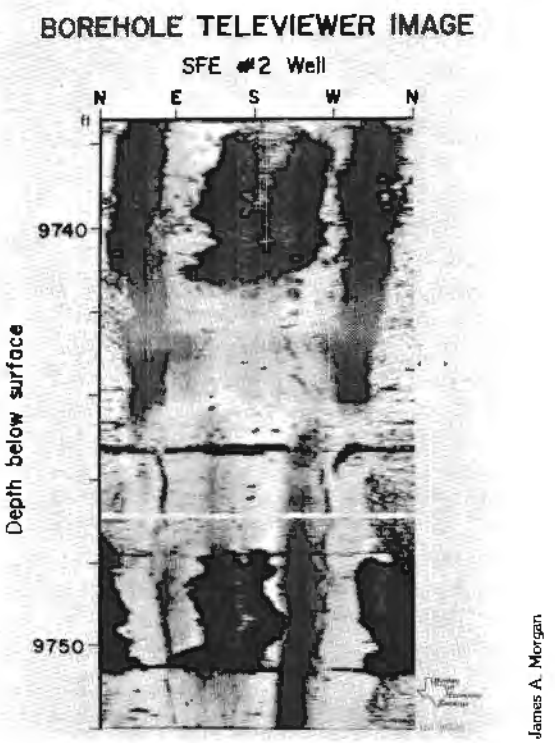
permeability sandstone in East Texas, North Louisiana, and southern Mississippi. This effort is part of a broader program designed to increase the understanding and ultimate utilization of unconventional gas resources through integration of multiple disciplines involved in gas resource development in formations having low permeability, particularly geology, log analysis, and reservoir engineering. At present, many low-permeability, gas-bearing sandstones are not being efficiently evaluated, hydraulically fractured, or produced because of a lack of appropriate technology to stimulate development of the gas resource at competitive prices.

Research in 1987 focused on locating, drilling, and evaluating the second Staged Field Experiment (SFE) well. In addition, regional studies of the depositional history, diagenesis, and structural evolution of the Travis Peak in East Texas continued, along with further analysis of data generated from the first SFE well, which was drilled in 1986. Geological results are being integrated with geophysical well logging and reservoir engineering research conducted by other contractors to GRI.

Geological characterization of several fields in East Texas was undertaken to locate a site for the second SFE well. Criteria including depth to the reservoir zone, proximity to existing low-permeability reservoirs, thickness and lateral continuity of reservoir zones, typical fracture treatments, and production were used to evaluate the fields. Consideration of these factors resulted in selection of North Appleby field, Nacogdoches County, as the site for the second SFE well. The well was drilled through the Travis Peak Formation to a total depth of 10,163 ft, and 360 ft of core from four zones was recovered. Cased-hole experiments and completion of this research well will continue into 1988.

Stratigraphic studies of the Travis Peak Formation of East Texas are progressing along two major research trends—regional basin analysis and detailed field studies. Regional and subregional stratigraphic correlations and interval mapping are being carried out to delineate depositional systems in the Travis Peak and to understand how the basin evolved through time. Mapping has indicated that several shale horizons in the deep basin possibly extend regionally from western Louisiana and southeast Texas into updip, sand-rich marginal-marine and continental deposits. If these shales represent significant divisions in the Travis Peak and are regionally mappable, they could represent transgressive events that divide the Travis Peak into four or five depositional sequences.

A detailed study of North Appleby field in northeastern Nacogdoches County has followed from the selection and drilling of the SFE No. 2 well. Well logs from about 35 wells, and cores from the Prairie Mast No. 1-A and the SFE No. 2 wells (total of 584 ft), provide an optimal data base for reservoir studies. Travis Peak sandstone and mudstone in North Appleby



Data from a borehole televiewer, a tool used for detecting fractures and determining in situ stress directions, for a well in East Texas showing breakouts (dark irregular feature at 9,748–50 ft) at right angles to a fracture (thin dark line trending NE-SW). Both features indicate that minimum horizontal stress is oriented NW-SE. These data are being studied as part of the Low-Permeability Gas Sandstone Reservoirs project.

field are interpreted to have been deposited in environments associated with major fluvial systems (active and abandoned channel, lacustrine, and floodplain environments) that evolved during Travis Peak deposition. Interpretation of cores suggests that fluvial systems evolved through time, changing from broad, low-sinuosity sand-rich channels during early deposition to relatively deeper low-sinuosity channels later.

Studies of diagenesis focused on the effect of cementation on permeability and reservoir quality. Coring of the SFE No. 2 well provided an opportunity to study the effect of drying on morphology of authigenic illite. Following extensive quartz cementation in the Travis Peak, fibrous authigenic illite occluded much remaining pore space. When core samples of the reservoir rock are exposed to air and dry, illite fibers clump together and collapse against pore walls. This process occurs in scanning electron microscope (SEM) samples, where it changes the appearance of the illite, as well as in core plugs, where it increases the permeability of the plug over its in situ value. Experiments on the SFE No. 2 core indicate that freeze-drying the SEM samples improves preservation of original morphology. Investigations are in progress to quantify the effect that alteration of illite morphology has on permeability measurements of Travis Peak plugs.

Another reservoir-quality study on the effect of solid immobile hydrocarbons (reservoir bitumen) on the response of density and neutron logs indicated that both techniques may overestimate porosity in bitumen-bearing rocks. Reservoir bitumen is common in Travis Peak reservoirs, and point-count data indicate that where present, bitumen fills an average of 3 to 6 porosity units. However, some samples contain as much as 19 porosity units of bitumen, which would cause a large overestimation of porosity by density and neutron logs.

Structural studies in 1987 focused on analysis of natural and coring-induced fractures visible in core and on fracture-imaging geophysical logs from Travis Peak wells in East Texas. Petrographic and SEM studies indicate that fractures in Travis Peak sandstone are natural hydraulic fractures that formed during precipitation of quartz cement. The model developed to account for the microstructure of the natural fractures predicts that natural fractures should be most abundant in low-permeability Travis Peak sandstone. Evidence of this is provided by core from the SFE No. 2. Here, fractures with widths of as much as 5 mm exist in the subsurface in rocks with low permeability. Testing the significance of these results for formation evaluation and hydraulic fracture stimulation is a major objective of reservoir engineering tests currently in progress at SFE No. 2.

An important goal of well-log analysis is the detection of fractures. Two tools used for fracture detection are the borehole televiewer (BHTV) and the Formation Microscanner (FMS). A study based on a comparison of 1,130 ft of core from three wells with BHTV and FMS logs was undertaken to evaluate how well these tools detect and image fractures. Results of the study show that although these logs are useful adjuncts to core-based studies of fractured reservoirs, fracture studies based on logs alone still have many drawbacks.

Efficient hydraulic-fracture treatment of a low-permeability formation such as the Travis Peak depends on a reliable prediction of the strike of the stimulation fracture, which is generally parallel to the maximum horizontal stress. Strike of coring-induced fractures can be used to predict the strike of stimulation fractures if the fractures created during coring are also aligned with maximum horizontal stress. A study based on fracture descriptions of 565 fractures in more than 1,800 ft of whole core is in progress to determine the orientation of coring-induced fractures in East Texas and to compare the strike of coring-induced fractures to stimulation-fracture strike and natural-fracture strike. The vector mean strike of 78° for 101 coring-induced fractures is parallel to the strike of stimulation fractures, which were independently determined by surface and borehole seismicity. Coring-induced fractures are also parallel to five fractures created during hydraulic fracture stress tests and to the maximum horizontal stress direction determined from anelastic strain recovery and differential strain curve analysis.

Remote-sensing activities also yielded information about probable fracture propagation direction in Travis Peak sandstones by study of radar imagery covering the East Texas study area. This analysis revealed strong NE and NW lineament trends, consistent with regional trends previously mapped from smaller scale Landsat imagery and with regional subsurface stress. These studies were supplemented by detailed examination of wellbore ellipticity logs from seven wells. Previous studies in other basins have shown that the orientation of wellbore breakouts is consistently aligned with least compressive horizontal stress. Such a relationship in the Travis Peak could provide valuable information about in situ stress conditions in the vicinity of individual wells. In the East Texas study area, wellbore ellipticity with two predominant orthogonal orientations was demonstrated. The NW trend was interpreted to result from wellbore spalling parallel to regional least compressive stress, which is perpendicular to the Gulf coast. The NE trend was interpreted to result from erosion of the wellbore parallel to fractures. FMS and BHTV logs were used to identify stress-related spalls and fracture-controlled elliptical zones. Preliminary results indicate that the BHTV, with its ability to display the entire circumference of the borehole, is a powerful tool for studying the relationship between elliptical zones, spalls, and fractures.

Research on low-permeability, gas-bearing sandstones in 1988 will include continued testing and analysis of information from the SFE No. 2 well. In addition, geological characterization of new play areas will identify potential sites for the third SFE well, which will be drilled in 1988. Local depositional systems studies will contribute to development of a comprehensive model of regional depositional systems and reservoir potential of the Travis Peak Formation in East Texas. Similar models may also be extended to other formations. Structural studies will be a major component of research in 1988 as techniques used to analyze the natural fracture system and regional state of stress are refined. Petrographic and diagenetic work will continue to explore the relationship between petrophysical properties and petrographic parameters such as clay content, cementation, and grain size.

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

Robert J. Finley and Noel Tyler, project directors; Chester M. Garrett, Jr., and Elisabeth C. Kosters; assisted by Javier Luna-Melo, William E. Schramm, and Peter B. Stokes

This project, funded jointly by the Gas Research Institute and the Bureau, aims to synthesize critical information on the most productive onshore gas reservoirs in Texas. Publication will be in the form of an atlas, which will be a companion volume to the Bureau's 1983

"Atlas of Major Texas Oil Reservoirs." The gas reservoir atlas is scheduled for publication in the second half of 1988 and will be the first comprehensive publication on this important resource. In addition, the atlas will serve as a base for future studies on gas reserve growth of specific fields and plays, as well as for detailed field and subregional geologic analyses of reservoir heterogeneity.

Using a screening parameter of cumulative gas production of at least 10 billion cubic feet (Bcf), or the equivalent of 1.7 million barrels of oil, researchers selected 2,000 reservoirs for inclusion in the atlas. About one-third of these reservoirs have produced at least 30 Bcf and make up almost 85 percent of total cumulative production from the selected reservoirs. Characteristics of these reservoirs are emphasized and presented in more detail.

Reservoirs are grouped into 84 geologically distinct plays, each based on reservoir genesis, formation, lithology, trapping mechanism, petrophysical properties, and geographic location. Thirty-five plays are in the Gulf Coast province (Texas Railroad Commission [RRC] Districts 1 through 4). Another 10 plays are in the East Texas province (RRC Districts 5 and 6), 10 in the Texas Panhandle (RRC District 10), 22 in West Texas (RRC Districts 7C, 8, and 8A), and 7 in North-Central Texas (RRC Districts 7B and 9).

Within the Gulf Coast province, 60 percent of the production is from 10 Frio plays, the most prominent of which is in Jim Wells, Kleberg, and northern Brooks Counties. This play, also an important oil play with a considerable amount of associated gas, produces from sands of the Norias delta system, where hydrocarbons are trapped by large-scale growth faults along the Vicksburg shelf edge. Underlying Vicksburg fluvial-deltaic sediments also are an important play. Other major Gulf Coast plays are the Frio barrier bar/strandplain system, which is along the central Gulf Coast, and the Houston delta system, where trapping is influenced by salt tectonics. In addition, upper Wilcox delta systems, faulted over the Cretaceous shelf margin (in Bee, Live Oak, Duval, and Goliad Counties), form a significant play, as do lower Miocene fluvial sands in Refugio County, which produce over and along reactivated Frio faults on the landward side of the Frio barrier bar/strandplain play. On the average, only 11 percent of all Gulf Coast gas production is from reservoirs that occur below the top of geopressure. This proportion is higher in middle Frio reservoirs of the Hackberry embayment and in the adjacent growth-fault-dominated portion of the Houston delta system. Relatively large production also occurs from geopressured Vicksburg deltaic sands of Starr County and the lower Wilcox Rockdale delta system in De Witt and Karnes Counties.

In East Texas, on the Sabine Uplift, the most prolific play is from Lower Cretaceous shallow-marine limestones of the Glen Rose, Pettet, and Rodessa Formations. This play represents about 37 percent of total East Texas production, followed by Smackover limestones and dolomites of the West Tyler Basin, representing about 13 percent.

Natural gas production in West Texas, North-Central Texas, and the Panhandle is restricted to Paleozoic rocks, mostly carbonate. In North-Central Texas, reservoirs are Pennsylvanian and older. In the Panhandle they are Cambrian-Ordovician through Permian, and in West Texas, Cambrian-Ordovician through Permian (Guadalupian).

The largest plays in West Texas are from Silurian-Devonian and Ellenburger carbonates of the Delaware and Val Verde Basins and upper Pennsylvanian Canyon sandstones in the northern Val Verde Basin. Before the large nonassociated gas reservoirs in these plays were discovered, this region was considered primarily one of associated gas production. However, since the discovery of these nonassociated gas reservoirs, dry gas production from the Delaware and Val Verde Basins has increased from less than 20 percent to more than 50 percent of the cumulative production of the area.

North-Central Texas is dominated by the Pennsylvanian (Bend) conglomerate gas play. Coarse-grained delta and fan-delta deposits provide regionally extensive reservoirs.

Reservoirs in the Panhandle region are Permian (Leonardian) and older. The largest fields, Hugoton and Panhandle, are grouped into one play. These fields comprise several individual reservoirs that are related by common gas-oil and gas-water contacts. Sediments (granite wash) shed from the Amarillo Uplift and deposited in alluvial fan and fan-delta systems and shallow-water carbonates provide regionally extensive reservoirs that account for nearly 70 percent of the cumulative gas production of this region.

The gas atlas will cover more reservoirs and plays and be more comprehensive than the "Atlas of Major Texas Oil Reservoirs." The atlas plates will be drafted at a scale of 1:1,000,000, or twice as large as those in the oil atlas. Tables of reservoir characteristics will also be more extensive. A chapter will be included on statistical analysis of production figures on a play-by-play basis.

Geological and Engineering Research Support for Gulf Coast Co-production Program

Noel Tyler, project director; William A. Ambrose, Malcolm P. R. Light, and David W. Koppenaal; assisted by Timothy J. Jackson

The Gulf Coast Co-production program, funded by the Gas Research Institute, is designed to improve hydrocarbon production from gas reservoirs that have been abandoned or have begun to water out. The principal procedure used to recover gas from watered-out wells involves high-volume brine production by the brine level and the reservoir pressure, thus expanding

immobile gas until it again becomes mobile and migrates to the wellbore with the produced water.

The Bureau played a key role in selecting Frio deltaic reservoirs in Northeast Hitchcock field (Galveston County, Texas) for co-production testing. Large volumes of brine are expected to be produced from these gas reservoirs; from three wells in Northeast Hitchcock field, 22,500 barrels of brine must be disposed of daily. As a follow-up study, the Bureau determined the best sands in the overlying Miocene in Northeast Hitchcock field for disposal of these brines. By studying Miocene depositional units in Northeast Hitchcock field and the surrounding area and by documenting the brine-injection potential of Miocene sands in nearby fields, the Bureau selected four lower Miocene barrier-island and wave-dominated deltaic sands, each 50 to 110 ft thick, for brine disposal. Factors considered in selection of these sands were sand-body continuity, thickness, and previous brine-disposal history.

A brine-disposal well was drilled in Northeast Hitchcock field to intersect the thickest portions of the four brine-disposal sands. Three Miocene sands were cored. Core descriptions and petrographic analyses of cores were supplemented by a variety of engineering data such as permeability, pore-size distribution, cation-exchange capacity, and formation resistivity factors. Final recommendations for brine-disposal zones were made after review of all available geologic and engineering data. Results of initial brine-flow tests in the deepest disposal sand have been favorable. Accordingly, co-production in Northeast Hitchcock field has recently been resumed with expectation of successful brine disposal.

Consolidation of Geologic Studies of Geopressured Geothermal Resources in Texas

Noel Tyler, project director; Malcolm P. R. Light and H. Scott Hamlin; assisted by Timothy J. Jackson

This Department of Energy-funded program has been separated into two tasks: (1) special projects research and coordination assistance and (2) mesoscopic and microscopic analyses of rock samples utilized in rock mechanics studies.

Special Projects Research and Coordination Assistance

Malcolm P. R. Light and H. Scott Hamlin; assisted by Timothy J. Jackson

A major objective of this program is to develop a set of parameters that will enable private industry to determine the economic viability of a geopressured field using production data from a single test well. During 1987 testing procedures were developed for two such wells—Gladys McCall well in southwestern Louisiana and Pleasant Bayou well on the Texas Gulf Coast.

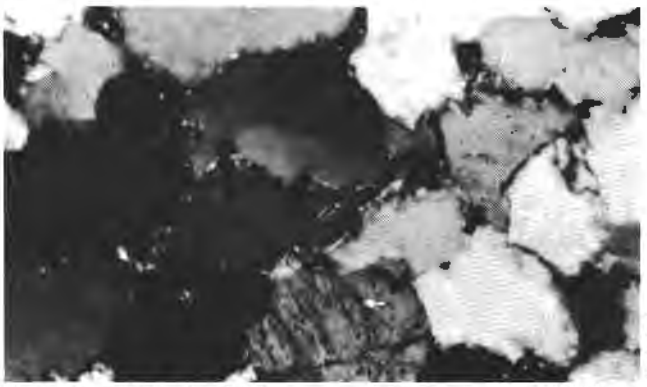
Production testing of the Gladys McCall well continued throughout 1987. Pressure declines during production of large volumes (10,000 barrels per day) of geopressured water indicate an apparent reservoir size three times larger than that predicted using data from geologic studies. Three hypotheses are proposed to account for the discrepancy: shale dewatering, reservoir compaction, and leakage along faults. A correlation between decreasing salinity and declining pressure suggests that low-salinity shale waters are flowing into the reservoir sandstone. Proposed testing includes closely monitoring the salinity/pressure relationship over an extended production period and obtaining samples of water from shales adjacent to the reservoir. To check for leakage along fault planes, it was proposed that chemical tracers be injected into a sandstone underlying the primary reservoir. To ascertain whether compaction of either the reservoir or enclosing shales has occurred, a program of sidetrack coring was proposed.

Production of geopressured geothermal waters from a lower Frio Formation reservoir in the Pleasant Bayou well will be resumed in 1988. An electrical-energy conversion system is being constructed on the site to test the economic feasibility of geothermal energy production. An additional source of energy will come from methane that is dissolved in geopressured waters. Testing procedures similar to those proposed for the Gladys McCall well will be implemented at Pleasant Bayou. The Bureau will also provide geologic and hydrologic assistance during workover and subsequent production testing of the Pleasant Bayou well.

Mesoscopic and Microscopic Analyses of Rock Samples Utilized in Rock Mechanics Studies

Malcolm P. R. Light; assisted by Timothy J. Jackson

This project was designed to complement detailed studies of rock mechanics being conducted at The University of Texas at Austin. Production of geopressured water will lower reservoir fluid pressures, increase effective stress on the sandstone framework grains, and potentially result in compaction, fracturing, and porosity reduction. Core samples from the Gladys McCall reservoir sandstone were artificially compacted to failure, and thin sections of both uncompacted and compacted samples were examined. The quartz-rich Gladys McCall sandstone has high rock strength because of naturally occurring pressure-solution contacts (stylolites) that interlock quartz and feldspar grains. Inelastic compaction attributable to grain rotation and deformation does not occur, and porosity is maintained. The Pleasant Bayou reservoir sandstone is more heterogeneous, consisting of quartz-rich zones as well as zones with abundant feldspar and rock fragments. Some inelastic compaction is expected during production at Pleasant Bayou. However, experimental compaction of feldspathic litharenite



T. J. Jackson

Photomicrograph of stylolitic contacts between quartz and feldspar grains, reservoir sandstone in the Gladys McCall geopressured geothermal well. Field of view is about 0.65 mm wide.

(Frio A reservoir) from the Northeast Hitchcock field, Galveston County, caused formation of through-going fracture systems that resulted in reduction of pore-fluid pressure by forming channels for fluid escape. Thus, compaction and fracture formation need not inhibit production at Pleasant Bayou.

Assessment of Gas Resources for Secondary Gas Recovery Technology

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

This program, which is funded by the Gas Research Institute (GRI), seeks to evaluate geologically based infill drilling and recompletion of bypassed gas zones as sources of increased gas reserves at competitive prices. Oil reserve growth, primarily from infill and extension strategies, has accounted for 84 percent of reserve additions for the period 1979–84. By analogy, gas reserve growth may have similar potential.

Major gas plays outlined by the Gas Atlas project (see p. 9) served as the basis for field selection. Two fields, La Gloria in Jim Wells and Brooks Counties and Julian in Kenedy County, were selected from the clastic, fluvial-deltaic Frio-Vicksburg gas play, the most productive nonassociated gas play in Texas. La Gloria field is located in the updip fluvial Frio trend along the Vicksburg fault zone. In contrast, Julian field is located in the downdip, wave-dominated deltaic Frio trend along the Frio fault zone. Sand-body continuity and reservoir connectivity will be contrasted between Julian and La Gloria fields. In the future, an additional South Texas field will be selected for study, along with two associated gas reservoirs from the prolific West Texas carbonate plays.

Depositional-facies and net-sand-thickness maps for La Gloria and Julian fields are the basis for statistical evaluation of pay continuity. Geologic characterization indicates that fluvial reservoirs in La Gloria field consist of dip-oriented, interfingering, multistoried sand bodies that contain several isolated compartments of gas. Preliminary evaluation of facies continuity shows limited connectivity in La Gloria field at 320- to 640-acre well spacings. Pressure analyses are used to quantify connectivity properties of different facies, which will allow volume estimates of untapped gas isolated by reservoir heterogeneities. Once pay continuity has been established for specific depositional environments, appropriate infill-drilling strategies can be defined. Volume estimates can be extrapolated to the play level and serve as the basis for evaluation of gas reserve growth potential in Texas and similar gas-producing provinces.

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

Robert J. Finley, project director; Shirley P. Dutton and Lee A. Jirik

Purpose of the Secondary Gas Recovery project, which is funded by the Gas Research Institute, is to develop and test methods to maximize recovery from conventional gas reservoirs in mature fields. Selected fields will be studied using advanced geological characterization to identify untapped compartments within established reservoirs, to evaluate bypassed gas reservoirs in existing wells, and to better delineate the potential for deeper-pool discoveries. Detailed facies analysis is being integrated with engineering and volumetric data to determine the degree of communication between compartments, thereby suggesting which facies contain the best potential for infill drilling or recompletion of bypassed zones. New approaches to the interpretation of recently introduced logging tools are being used to evaluate bypassed gas-bearing zones within producing intervals. Delineating deeper-pool discoveries in producing fields is a secondary objective that will involve prediction of hydrocarbon-bearing sandstones on the basis of inferred depositional systems.

During 1987, the project focused on Seeligson field, Jim Wells and Kleberg Counties, South Texas (Texas Railroad Commission District 4), which is being studied in cooperation with Sun Exploration and Production Company. Seeligson field contains a Sun-operated unit that produces gas from multiple, stacked fluvial-deltaic reservoirs in the Oligocene Frio Formation. The productive section, containing more than 25 reservoirs, is at depths of 4,100 to 6,300 ft. The stacking of fluvial and fluvial-deltaic facies at Seeligson field and the trapping of hydrocarbons on the downthrown sides of synsedimentary faults are characteristic of many producing fields in the gas-prone South Texas region.

The Bureau's present efforts focus on approximately 4 mi^2 in the east-central part of the Seeligson Unit. The stratigraphic framework has been established with a grid of cross sections that illustrate facies variability in these fluvially dominated reservoir sandstones.

Significant discontinuities in individual sandstones and changes in spontaneous potential log character are most evident in four zones that will be the focus of intensive geologic analysis. A cooperative well was drilled late in 1987 south of the area of detailed study. Data acquired for the project included 30 ft of whole core, sidewall cores, an open-hole sonic log, pressure data from several sandstones to determine degree of pressure depletion, and a full-waveform cased-hole sonic log to better understand the response of cased-hole neutron tools and supplemental porosity determinations in other wells.

Coal

North-Central Texas Bituminous Coal

W. B. Ayers, Jr.

Study of depositional settings of bituminous coals in the upper Pennsylvanian and lower Permian Harpersville Formation of North-Central Texas is continuing. A regional structure map on the top of the Saddle Creek Limestone shows that the Fort Chadbourne fault zone influenced the positions of Harpersville shelf margins, and it offsets Harpersville strata. However, the fault zone lies basinward of, and does not affect, Harpersville coal seams.

In the southern part of the study area, structural trends are discordant with isopach trends of the lower Harpersville but concordant with isopach trends of the upper Harpersville Formation. This change in isopach trends suggests that the Llano Uplift, which lies to the southeast, was absent during lower Harpersville deposition but may have been active during deposition of upper Harpersville sediments. This conclusion is supported by greater thicknesses of coarse-clastic sediments in the upper than in the lower Harpersville at the southern end of the study area.

Geology and Ground-Water Hydrology of Deep-Basin Lignite in the Wilcox Group of East Texas

W. R. Kaiser, project director; Graham E. Fogg

This study is a continuing effort to evaluate the Wilcox Group. Ultimately, three hydrological and geological folios will be published: (1) "The Wilcox Group and Carrizo Sand in the Sabine Uplift Area, Texas: Ground-Water Hydraulics and Hydrochemistry"; (2) "The Wilcox Group and Carrizo Sand in East-Central Texas: Ground-Water Hydraulics and Hydrochemistry"; and (3) "The Wilcox Group (Paleocene-Eocene) in the Sabine Uplift Area, Texas: Depositional Systems and Deep-Basin Lignite." Folios will feature maps (scale: 1 inch = 6 mi), regional cross sections, and tabulated supporting data (microfiche appendix), along with a short interpretive text. Unpublished maps, cross sections, and supporting data for all folios are available for use at the Bureau.

Computerized Calculation of Lignite Resources in Texas

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

This ongoing project, funded by the U.S. Geological Survey (USGS) since 1979, provides estimates of remaining near-surface lignite resources (those under less than 500 ft of cover) in Texas. The computerized data base and graphics software of the National Coal Resources Data System (NCRDS) are used to calculate resources according to criteria of USGS Circular 891. No resources were calculated in 1987, pending digitization by the USGS of point-source data for the Jackson/Yegua trend in East Texas.

Organic Petrography and Geochemistry of Texas Lignite

W. R. Kaiser, project director; Prasanta K. Mukhopadhyay

This project, funded by the U.S. Geological Survey under its National Coal Resources Data System program and State-appropriated funds, began in 1985 and was completed this year. A report on the organic petrography and geochemistry of Texas lignite is being edited for publication as a Bureau Report of Investigations.

The report presents extensive data on huminite reflectance, maceral composition, and Rock-Eval pyrolysis as well as ancillary data on coal quality, bitumen extract/gas chromatography, and anhydrous/hydrous pyrolysis-gas chromatography. Reflectance (~50 R_o measurements/sample) and maceral data (21 macerals/sample) are reported for 155 samples (117 Wilcox and 38 Jackson) collected statewide from active surface mines (10), known deposits (2), deep-basin boreholes (11), and most lignite-bearing stratigraphic intervals.

Huminite reflectance and calorific value suggest that Wilcox coals are borderline subbituminous C to lignite in rank, whereas Jackson coals are lignite in rank. Maceral analyses clearly show that Texas lignites are liptinitic in character. Ternary diagrams of maceral composition were used to define organic facies consistent with interpretation of peat-forming environments (swamp, swamp-marsh, and marsh) made from earlier Bureau subsurface geologic mapping. Wilcox lignites of northeast Texas and the Sabine Uplift area have the petrographic character of arboreal swamps and accumulated highest on the paleoslope. Wilcox lignites of east-central Texas and Jackson lignites of East and South Texas accumulated mainly in swamp-marsh complexes and/or marshes lower on the paleoslope. Texas lignites are classified as humic,

mixed, or sapropelic and occur within the Type II and Type III kerogen maturation paths. Mixed and sapropelic coals are thought to be derived from alginite and cutinite, whereas humic coals originate mainly from huminite and sporinite. Mixed coal is a potential source of liquid hydrocarbons.

Geologic Evaluation of Critical Production Parameters for Coalbed Methane Resources

Robert J. Finley, project director; W. B. Ayers, Jr., project manager; W. R. Kaiser; assisted by J. C. Fiduk and Thomas E. Swartz; in cooperation with the Geological Survey of Alabama, Colorado Geological Survey, and New Mexico Bureau of Mines and Mineral Resources

Coalbed methane is natural gas that is produced from wells completed in coal seams. Methane resources in coalbeds of the United States are estimated to be between 200 and 800 Tcf; estimated recoverable resources are 10 to nearly 500 Tcf. These ranges in estimates reflect geologic uncertainties associated with an industry in its infancy; evaluation of coalbed methane resources in the United States began in the late 1970's, and systematic development of the methane began in the early 1980's. Exploration and development technologies have not reached levels of sophistication common to the oil and gas industry in general. Recognizing that a greater understanding of geologic controls on coalbed methane genesis and recovery is essential to both exploration and production, the Gas Research Institute in August 1987 awarded the Bureau a 2-year contract to study the San Juan and Black Warrior Basins, the leading producers of coalbed methane in the United States.

The Bureau is the principal researcher for coalbed-methane studies of the Fruitland Formation (Upper Cretaceous) of the San Juan Basin; the Colorado Geological Survey and New Mexico Bureau of Mines and Mineral Resources are cooperating through subcontracts in studies of the San Juan Basin. The Geological Survey of Alabama is studying coalbed methane in the Pottsville Formation (Lower Pennsylvanian) of the Black Warrior Basin under a subcontract with the Bureau.

Geologic and hydrologic factors such as sand-body geometry, coal seam continuity, permeability, and ground-water flow regime interact to determine availability and producibility of coalbed methane. The relative importance of these factors in the San Juan and Black Warrior Basins will be assessed in integrated studies of depositional systems, hydrology, fracture systems, gas geochemistry, thermal maturation, and histories of producing wells. Objective of the research is to develop exploration models that will reduce exploration costs and optimize recovery of this gas resource.

Land, Water, and Environmental Resources Investigations

Waste Isolation Studies

Geological and Hydrogeological Evaluations of the Texas Panhandle for a Potential High-Level Waste Repository

The West Texas Waste Isolation project, initially funded by the U.S. Department of Energy in 1977, has resulted in compilation of a massive data base on the Palo Duro Basin. Bureau personnel have published more than 250 reports and abstracts based on their investigations of the area.

In 1987, a major effort was devoted to development of programmatic planning documents requested by the Salt Repository Project Office of the Department of Energy, including activity plans, site study plans, and geological, geohydrological, and geochemical components of a Site Characterization Plan. A highlight of the year was a Bureau-sponsored symposium on and field trip to the Ogallala and Blackwater Draw Formations, which drew researchers from around the country. Papers representing diverse areas of interest were presented, including discussions of stratigraphy, pedology, paleoclimate, and formation of playa lake basins.

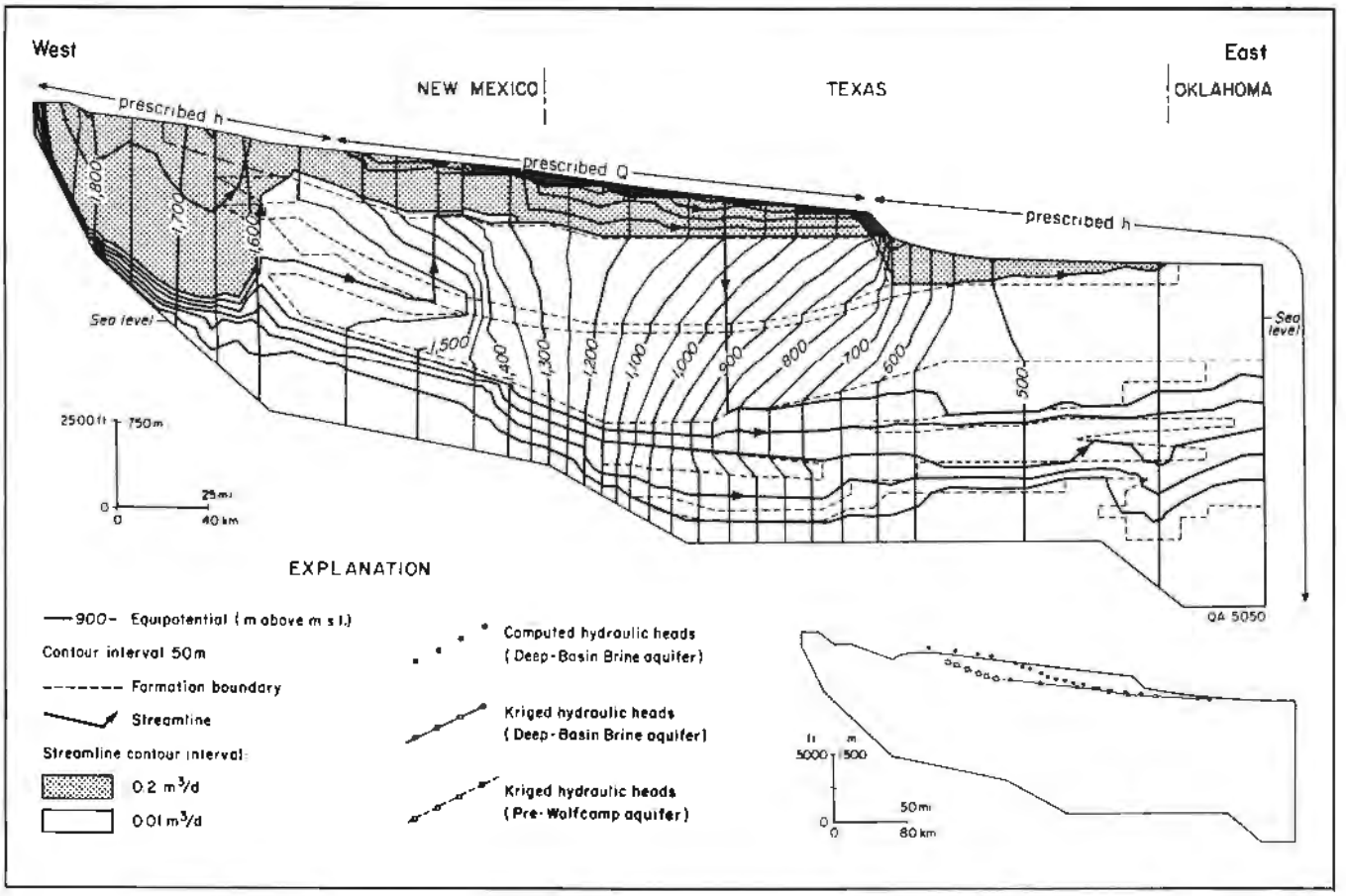
Research conducted in 1987 by the three program areas—Structural and Stratigraphic Geology, Hydrogeology, and Geochemistry—is summarized below.

Structural and Stratigraphic Geology Program

Marcus E. Milling, program director; Jay A. Raney, principal investigator; S. Christopher Caran, Bernard Célérier, Edward W. Collins, Robert D. Conti, Jules R. DuBar, Thomas C. Gustavson, Martin P. A. Jackson, Stephen J. Martel, H. Seay Nance, and Stephen C. Ruppel

Key issues addressed by this group in 1987 included

- Geologic Framework: Description of the distribution and character of regional and local strata and



Flow net from finite-element simulation of paleohydrologic ground-water flow patterns preceding erosion of the Pecos River valley and isolation of the Southern High Plains during the late Tertiary and early Quaternary. The model results suggest that across the western side of the basin there may have been significant upward-directed discharge into the shallow aquifer system overlying Permian evaporites. Numerical models are useful tools to test hypotheses of what hydrogeologic, climatic, and other parameters control past, present, and future ground-water flow velocities.

structures for improved understanding of geologic, hydrologic, and geochemical processes

- Surficial Processes: Analysis of rates and effects of erosion and playa formation
- Paleoclimate and Prediction: Studies of past climate as it may relate to future climate
- Paleoseismicity and Stability: Estimation of magnitude or intensity of prehistoric seismic events and assessment of effects of future earthquakes

A series of integrated structural and stratigraphic investigations focused on Cenozoic geomorphic and depositional processes, Mesozoic and Paleozoic stratigraphy, neotectonics, remote sensing, and basin development. Studies of pre-Cenozoic stratigraphy concentrated on Permian stratigraphic units, including the San Andres Formation. Studies of Wolfcamp facies distribution, depositional environment, diagenesis, mineralogy, and geochemistry were initiated.

Publications issued in 1987 on structure and stratigraphy include Miscellaneous Map No. 37, "Structure-Contour Map on the Lower Permian Red Cave Formation, Panhandle Field and Adjacent Areas of the Texas Panhandle," Geological Circular 87-5, "Rock Fabric, Permeability, and Log Relationships in an Upward-Shoaling, Vuggy Carbonate Sequence," and Report of Investigations No. 162, "Erosion Rates and Processes in Subhumid and Semiarid Climates, Texas Panhandle: Statistical Evaluation of Field Data."

Hydrogeology Program

Marcus E. Milling, program director; Alan R. Dutton, principal investigator; Amos Bein, Ronit Nativ, Bernd C. Richter, and Rainer K. Senger, assisted by Arten Avakian, Gay Nell Gutierrez, Scott Lawless, Tony Lee, and Michael Vecchio

Issues investigated by the Hydrology program staff in 1987 included

- Aquifer Characterization: Determination of flow paths and velocities of water moving across the evaporite section to ascertain whether prevalent flow is by percolation through porous media or through fractures
- Water Resources and Quality: Assessment of water resources and quality in terms of aquifer recharge rate, primary recharge mechanism, and ground-water production

Interconnected with the Ogallala aquifer beneath the southern part of the Southern High Plains are aquifers in Cretaceous Edwards, Trinity, and Fredericksburg Groups. Potentiometric surfaces indicated that groundwater flow is southeastward; as in other hydrostratigraphic units in the basin, principal flow directions reflect the influence of surface topography. Hydrochemical facies vary considerably between the Cretaceous formations, reflecting differences in sandstone and carbonate rock type and amount of vertical circulation within the aquifer system. Research in 1987 suggested that the confined aquifer system in the Triassic Dockum Group (Santa Rosa Formation) is hydrologically distinct from the overlying High Plains aquifer system and that the confined Dockum aquifer beneath the Southern High Plains has not been recharged since Pleistocene erosion of the Pecos River valley separated the confined aquifer from its previous recharge areas.

With the assistance of many petroleum companies, Bureau staff collected approximately 60 brine samples from oil fields in the Texas Panhandle. Preliminary results of regional mapping of approximately 400 analyses of brine chemical composition throughout deep-basin brine aquifers and evaporite confining systems suggest that meteoric water with a high Na/Cl ionic ratio has moved into and eastward through deeply buried formations in the Palo Duro and Midland Basins, displacing connate water with a low Na/Cl ratio. A broad zone of mixing between meteoric and connate water is interpreted. A "piston-type," or displacive, flow model appears to be valid.

Publications issued in 1987 on hydrogeologic subjects include Geological Circular 87-2, "Hydrogeologic and Hydrochemical Properties of Salt-Dissolution Zones, Palo Duro Basin, Texas Panhandle—Preliminary Assessment," Report of Investigations No. 165, "Effects of Hydrostratigraphy and Basin Development on Hydrodynamics of the Palo Duro Basin, Texas," articles in the Geological Society of America Bulletin and *Water Resources Research*, and several contract reports and abstracts.

Geochemistry Program

Marcus E. Milling, program director; Jonathan G. Price, principal investigator; William R. Kaiser, R. Stephen Fisher, Susan D. Hovorka, David A. Johns, Jeffrey N. Rubin, David W. Koppenaal, Thomas L. Pinkston, Zvi Sofer, Steven W. Tweedy, Chris Lewis, Paul L. Knauth (Arizona State University, Department of Geology), and Harry H. Posey; assisted by Susan Ide, Mark E. Erwin, Guoqiu Gao, Steve Lin, Harris S. Cander, and Jonathan Blount

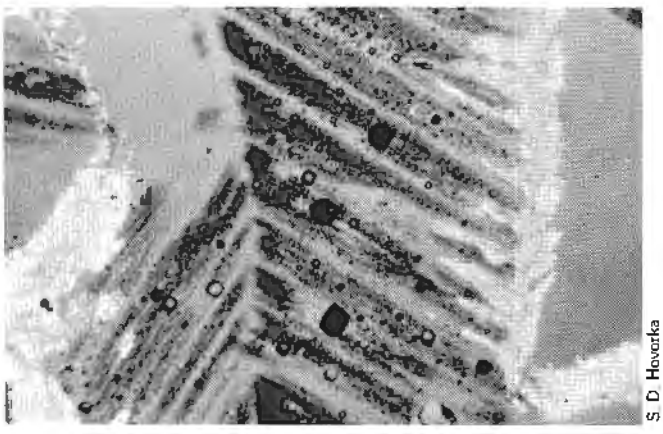
Key issues addressed by the Geochemistry program staff in 1987 included

- Host Rock Geochemistry: Characterization of regional chemical and mineralogical environments
- Potential Fluid Flow Paths: Evaluation of geochemical data to ascertain whether fluids have moved through the salt section since the Permian Period, 245 million years ago, and whether radionuclides could escape through the salt
- Radionuclide Retardation: Assessment of whether radionuclides might be retarded by sorption onto minerals encountered along the fluid path or by chemical precipitation.

Geochemical characterization of the thick salt with clastic interbeds in the lower San Andres unit 4 incorporated mineralogical and chemical analyses of samples selected from cores drilled in the Palo Duro Basin by the Department of Energy. The detailed petrographic descriptions and mineralogical determinations, coupled with certain chemical analyses, answered questions concerning environments into which radionuclides could migrate and retardation of radionculides through processes of sorption and precipitation. Geochemical investigations of the Permian strata focused on characterization of the salt, including halite, anhydrite, dolomite, and other minor phases and fluids within the salt, and of the clay-rich clastic interbeds in the salt section.

Much effort was placed on studies of diagenesis of the evaporites and interlayered clastic and carbonate rocks. The hypothesis that all diagenesis took place during Permian time, shortly after deposition, continued to be tested with petrographic studies, electron microprobe analyses of diagenetic phases, stable isotopic analyses of diagenetic phases and fluid inclusions, bromide analyses of halite and fluid inclusions, and X-ray diffraction studies and rubidium-strontium isotopic analyses of clays.

Diagenesis of the Triassic Dockum Formation, the clastic section above the Permian evaporites, was also investigated. The Dockum Formation is the lower part of the major aquifer system that stratigraphically overlies the San Andres salt interval. Diagenesis of the Dockum Formation may relate to Tertiary or Qua-



S. D. Hovorka

Photomicrograph showing fluid inclusions in halite that define an upward-pointing chevron, a texture preserved since original deposition in the Permian Period. Field of view is about 8 mm wide.

ternary fluid flow within the aquifer or to earlier fluid migration. In situ albitization of Dockum feldspars was recognized, indicating the presence of a sodium-rich fluid during diagenesis. Whether this fluid was a connate Triassic water or was derived from underlying Permian salt beds remained uncertain.

Publications issued in 1987 on geochemical subjects include Report of Investigations No. 166, "Origin and Evolution of Deep-Basin Brines, Palo Duro Basin, Texas," Geological Circular 87-3, "A Saponite and Chlorite-Rich Clay Assemblage in Permian Evaporite and Red-Bed Strata, Palo Duro Basin, Texas Panhandle," a contract report titled "Cross-Formational Flow in the Palo Duro Basin, Texas Panhandle," and four abstracts published in conjunction with the Conference on American Current Research on Fluid Inclusions and the Society of Economic Paleontologists and Mineralogists midyear meeting.

Low-Level Radioactive Waste Disposal

C. W. Kreitler, project director; J. A. Raney, W. F. Mullican III, E. W. Collins; assisted by K. Webb

At the request of the Texas Low-Level Radioactive Waste Disposal Authority, the Bureau continued geologic and hydrologic investigations of four potential low-level radioactive waste disposal sites in Trans-Pecos Texas. One additional site, the Laska Siding site, located approximately 10 mi west of Sierra Blanca in Hudspeth County, was investigated to provide a preliminary data base of the surface and subsurface geologic setting, stratigraphy, structural geology, and hydrogeology. Geology and rock characteristics that might affect porosity and permeability were mapped and described in support of hydrologic investigations. Prime hydrologic concerns at Laska Siding were depth to water table, permeability of potential host sediments and rocks, and rates and direction of ground-water flow. A drilling program was conducted for stratigraphic control and to provide a test borehole for hydrologic investigation.

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

Charles W. Kreitler and M. Saleem Akhter; assisted by Andrew Donnelly and Warren T. Wood

The Bureau has conducted a 2-year program to characterize regional hydrogeology of Tertiary saline sandstone strata in the Texas Gulf Coast Basin, for evaluating the suitability of these formations for continued deep-well injection of chemical wastes. This study, funded by the U.S. Environmental Protection Agency, has focused on hydrology and hydrochemistry of the Frio Formation. Regional pressure-depth profiles and potentiometric surface maps were constructed from bottom-hole-pressure data to identify different pressure regimes and regional fluid flow trends. Extensive hydrocarbon production seems to have caused widespread depressurization within productive plays of the Frio, enhancing flow potential of injected fluids toward oil and gas fields. Residual potentiometric surfaces of discrete depth intervals of the Frio have been prepared to assist in the investigation of local trends and cross-formational flow potential. Pressure-depth profiles and potentiometric maps of individual counties are being evaluated to determine influence of the variability in formation brine density and bottom-hole pressures. These maps can be integrated with local geologic properties and reservoir parameters to better define hydraulic continuity and fluid flow velocities.

Techniques developed by this investigation at the Bureau are available to the Texas Water Commission and to private industry for developing hydrodynamic models that could be used in the repermitting process for chemical waste disposal wells.

Geology and Ground-Water Hydrology of the Edwards Recharge Zone, Williamson County

Charles W. Kreitler and Christopher D. Henry, project directors; Edward W. Collins and Rainer K. Senger

A geologic and hydrologic study of the Edwards aquifer in Williamson County, funded by the Texas Water Development Board, was completed in 1987. Geologic and structural maps of the Balcones Fault Zone in the vicinity of Georgetown and Round Rock, Texas, were prepared in support of local and regional hydrologic investigations. Geologic and structural maps prepared in conjunction with detailed characterization of fractures in Edwards aquifer strata (Comanche Peak, Edwards, and Georgetown limestones) are useful for identification of potential recharge areas and assessment of local ground-water flow. Cretaceous strata from the Comanche Peak through Austin Formations, Quaternary surficial units, and faults and fractures of the Balcones Fault Zone have been mapped to better understand the distribution of permeability and porosity. The Edwards Limestone constitutes the principal part of the aquifer, but associated limestones in the Comanche Peak and Georgetown Formations may compose part of the aquifer. Comanche Peak and Georgetown limestones generally have lower permeability values than Edwards limestones, but fracturing associated with faults may have created localized areas of greater recharge potential.

The hydrogeologic investigation was designed to characterize recharge and discharge mechanisms and hydrochemical facies in the northern segment of the Edwards aquifer along the Balcones Fault Zone in the Austin area, with specific emphasis on Georgetown and Round Rock. Regional ground-water flow is characterized by steep hydraulic gradients indicating

relatively rapid flow in the western part of the aquifer with major discharge points along faults and fractures just east of the Edwards outcrop. Tritium concentrations are relatively high in the western part of the aquifer, also indicating relatively fast ground-water flow circulation. Some ground water bypasses these discharge sites and flows into the eastern part of the confined aquifer under low hydraulic gradients, indicating a slow-circulating flow system. Continuous water-level records from this study show that some wells respond very quickly to individual recharge events, whereas others exhibit a delayed response or none at all. Rapid water-level responses suggest local recharge by leakage along faults and fractures through the Georgetown Formation into the subjacent Edwards Formation.

Hydrochemistry of Edwards water indicates a chemical evolution of ground-water types from calcium bicarbonate and calcium-magnesium bicarbonate to mixed bicarbonate, and farther downdip to sodium bicarbonate, and finally to sodium-mixed water. Elevated nitrate concentrations in the confining section of the aquifer may point to shallow pollutant sources reflecting possible recharge along faults and fractures across the confining unit.

Texas Nuclear Waste Program

L. F. Brown, project director; Steven J. Seni, principal investigator; Bridget Scanlon and William F. Mullican III

In 1985, the U.S. Department of Energy (DOE) selected a 9-mi^2 area in Deaf Smith County for site characterization to test the feasibility of the area as a repository for high-level nuclear waste. The Texas Nuclear Waste Program, funded by an interagency grant from the Texas Governor's Office and approved by DOE, had two components—Office of Technical Review (OTR) and Geoscience Studies—in which the Bureau participated in 1987.

The principal task of OTR was review of technical documents, such as site characterization and land acquisition plans, for the Governor's Office. Geoscience research conducted at the Bureau in 1987 included a literature review and proposal of future research topics. The literature review integrated all available information on the geology and geohydrology of the Palo Duro Basin. Research plans submitted to the Governor's Office proposed hydrologic, stratigraphic, and structural investigations of the High Plains.

Geochemical Reactions between Injected Chemical Wastes and Host Rock

Regina Capuano and Charles W. Kreitler

Each year in the United States, 8 to 9 billion gallons of liquid-hazardous waste are disposed of by deep-well injection. In recent legislation, the U.S. Environmental Protection Agency (EPA) has been mandated to limit injection of hazardous waste unless it is proven that wastes will not migrate out of the injection zone within 10,000 years. Little is known about how or if the transformation of the waste in the subsurface limits its mobility.

The EPA Office of Drinking Water is funding a program at the Bureau to study waste degradation reactions. Initially data on compositions and volumes of waste injected into deep aquifers in Texas were compiled from permit applications and reports on file at the Texas Water Commission. Texas injection wells were selected for this study because more than 70 percent of industrial waste disposal by deep-well injection is conducted in Texas. This data base includes a compilation of more than 100 different waste streams into which more than 200 different organic and inorganic chemicals are disposed. Wastes are currently being subdivided into chemical groups having similar reactivities. Degradation reactions of the more commonly injected and hazardous waste groups will be studied through calculation of waste reactions using chemical equilibrium and mass transfer reaction codes. Calculations will be augmented through comparison with analogous situations, both natural and artificially produced, and with results of laboratory experiments described in the literature.

Sources of Salt-Water Pollution in Western Tom Green County

Charles W. Kreitler, Bernd C. Richter, and Alan R. Dutton

This investigation was designed to characterize chemically and isotopically any specific sources of brine that may pollute shallow ground water in Tom Green and eastern Irion Counties. The study followed a pilot project that indicated that brines from oil fields and natural ground-water discharge most likely contribute to the generally poor quality of ground water in the Concho River drainage basin. During 1986, investigations of the regional distribution of poor-quality ground water in Permian formations indicated that poor water quality is caused by natural discharge of briny ground water flowing eastward across the Eastern Shelf of the Midland Basin. The 1987 study tested specific salt sources to determine importance of (1) possible leakage from abandoned wells and boreholes, (2) abandoned oil-field brine disposal pits, and (3) abandoned water wells that were accidentally drilled into saline aquifers. These goals were accomplished by drilling shallow monitoring wells close to suspected leaky abandoned boreholes and at old abandoned brine-disposal pits. High chlorides at sites of both types of potential leakage indicate that both sources contribute saline waters. The concept that water wells had previously been drilled too deep and permitted to leak saline waters into shallower formations could not be confirmed.

Coastal Studies

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

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

Work continued through 1987 on this long-term comprehensive inventory of Texas coastal submerged lands and associated wetlands. Previous funding was provided by the Minerals Management Service, U.S. Department of the Interior, and by 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. A major objective of the study is to produce an extensive data base characterizing submerged lands and wetlands along the entire Texas coast from Sabine Lake to the Rio Grande. The submerged lands study 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 are being mapped and described using color-infrared photographs and field surveys.

The submerged lands atlas of the Beaumont-Port Arthur area, fourth in the series of seven that will cover the entire Texas coast, was published in 1987. The Corpus Christi, Galveston-Houston, and Brownsville-Harlingen volumes were published previously. Editing of the Bay City-Freeport text was completed in 1987, and the Port Lavaca text was submitted to peer review during the latter part of the year. Both atlases are expected to be published in 1988, followed by the atlas of the Kingsville area, which will complete the series. By the end of 1987, textural and geochemical maps of the Bay City-Freeport area were completed and much progress had been made on maps of the Port Lavaca area. The atlases consist of a text and a series of 17 maps: 4 maps (scale 1:250,000) depicting the distribution of sediment textures, 12 maps (scale 1:250,000) depicting concentrations and distributions of selected trace, minor, and major elements in sediments, and 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.

Delineation of coastal wetlands and associated environments continued in 1987. One objective of the study is to produce updated regional full-color maps of wetlands; units are patterned after the Bureau's *Environmental Geologic Atlas of the Texas Coastal Zone* series. Wetland maps of the Bay City-Freeport, Port Lavaca, and Kingsville areas are in various stages of hand-coloring, editing, and cartographic preparation. The first color proof of the wetlands map of the Bay City-Freeport area was completed during 1987. Comparison of the distribution of wetlands mapped on photographs taken in 1979 as part of the Submerged Lands project with those mapped for the *Environmental Geologic Atlas* on mid-1950's photographs indicates that although changes occurred in the Bay City-Freeport area, they were not as extensive as those that took place during the same period 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.

Shoreline and Vegetation-Line Changes along the Texas Coast

Jeffrey G. Paine, William A. White, and Robert A. Morton

Texas coastal lands are increasingly used for residential construction, recreation, resource exploitation, and industrial development. This heavy usage, combined with unique hazards posed by storms, sea-level rise, and subsidence, creates the need for monitoring change of coastal boundaries. During 1987, monitoring efforts were focused on long-term shoreline changes along San Antonio Bay and short-term changes in the Gulf shoreline and vegetation line.

Long-term movement of bay shorelines is determined by comparing shorelines depicted on late 1800's topographic charts and aerial photographs taken between 1930 and 1982. In addition to quantifying shoreline changes, these investigations encompass identifying shoreline types, analyzing causal agents such as storms, streamflow, and sea level, and interpreting shoreline movement. Results of the San Antonio Bay study were published in 1987 in the Bureau's Geological Circular 87-1, "Historical Shoreline Changes in San Antonio, Espiritu Santo, and Mesquite Bays, Texas Gulf Coast," by William A. White and Robert A. Morton.

In contrast to generally low rates of change along bay shorelines, Texas Gulf shorelines can change rapidly. Higher rates of movement along Gulf shorelines are caused by greater tide range, higher wave activity, more severe storm processes, and the presence of more unconsolidated sediment than occurs along most bay shorelines. Many significant changes have occurred since studies of long-term shoreline and vegetation-line changes along Gulf beaches were published between 1974 and 1977. To update these reports, Gulf shoreline changes between 1974 and 1982 were documented at more than 300 sites between Sabine Pass and the Rio Grande. During this period, which was characterized by relatively stable sea level, lower-than-average storm frequency, average streamflow, and average rainfall, shorelines and vegetation lines were predominantly recessional. There was a net land loss of about 330 acres and a net loss of beach vegetation of about 2,000 acres

between 1974 and 1982. Results of this study are scheduled to be published in 1988.

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

Robert A. Morton, project director; William A. White

Anticipated decline in oil and gas discoveries in the Gulf of Mexico has prompted the Minerals Management Service, U.S. Department of the Interior, to identify and locate nonfuel mineral resources that would stimulate future leasing within the Exclusive Economic Zone (EEZ). Nonfuel resources of the Texas Outer Continental Shelf identified as having economic potential include sand, gravel, and some heavy minerals. Locations, composition, approximate volumes, and quality of these deposits are currently being investigated using descriptions of short gravity cores and soil borings as well as interpretations of high-resolution seismic surveys. Objectives during the first year of study, which began in late 1987, are to determine the suitability of existing data bases and to select sites for more detailed field investigations, which would employ additional geophysical surveys and vibracores.

Monitoring the Beach and Vegetation Line on Galveston Island

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

In August 1983 Hurricane Alicia crossed the Texas coast, causing substantial beach erosion and extensive damage to houses near the shoreline. Scouring action by storm waves and currents undermined many homes, destroyed bulkheads, and caused landward retreat of natural vegetation. The purpose of this study, supported by the Office of the Texas Attorney General, is to provide current information concerning magnitudes and rates of recovery of the beach and vegetation line after a major storm. Also under study is the influence of human activities on recovery processes. This information should prove useful to owners of coastal property that is subject to storm damage and to public officials responsible for reviewing and permitting activities in the Coastal Zone. The study involves examining recent aerial photographs and measuring the beach profile at selected sites in undeveloped areas of West Beach, Galveston Island. Results of the field work more than 4 years after Hurricane Alicia show that dunes are reforming in undeveloped areas but not in developed areas; furthermore, the backbeach is still lower than before the storm.

Mineral Resources Investigations

Assessment of the Sulfur Resource Potential of State-Owned Lands

Tucker F. Hentz, Jonathan G. Price, and Gay Nell Gutierrez

A project to assess the potential for additional sulfur resources on State-owned lands in the Trans-Pecos region was completed in 1987. The project was jointly funded by the General Land Office and the Texas Mining and Mineral Resources Research Institute. A sulfur exploration model, derived largely from the literature and involving the presence of near-surface anhydrite or gypsum deposits, biogenic reduction of sulfate and oxidation of hydrocarbons, circulating meteoric ground water, and the presence of fractures and structural traps, was used in the assessment. Structural and stratigraphic controls on sulfur mineralization in the Rustler Springs (Culberson and Reeves Counties) and Fort Stockton (Pecos County) districts were investigated using a combination of surface and subsurface exploration methods. In both districts sulfur has been produced from Permian evaporite sequences. Pennzoil's Culberson mine, which has produced more than 28,000,000 tons of sulfur since 1969, is the premier deposit of the Trans-Pecos region and one of the largest Frasch-type mines in the world.

Sources of data for this investigation were General Land Office log files (approximately 1,400 exploration wells drilled during 1967 to 1970), reports available in the literature and in public files of State agencies, hydrocarbon distribution maps, and aerial photographs. Regional cross sections were constructed for stratigraphic control, and then various isopach and structure-contour maps were drawn. Lineaments interpreted from aerial photographs to be subsurface fractures aided in determining fault orientations. Maps of depths and thicknesses of sulfur occurrences detected during drilling were also incorporated in the assessment. Resource potential maps were constructed by overlapping from individual maps those areas that are considered to be most favorable for sulfur-ore formation. Some tracts of land in the sulfur districts of Trans-Pecos Texas also have at least moderate potential for future production of barite, brine, gypsum, limestone, potash, salt, strontium, and zinc.

Results of the investigation were reported in a contract report to the General Land Office in July 1987.

A detailed report containing pertinent maps and cross sections is being reviewed for publication by the Bureau. In addition, data used to construct individual maps and numerical tract-by-tract assessments of State-owned lands will be available on floppy disks. The reports are intended to aid industry in exploration and the State in land management.

Igneous Petrogenesis and Ore Deposition

Jonathan G. Price, Christopher D. Henry, Jeffrey N. Rubin, David W. Koppenaal, Steven W. Tweedy, Thomas L. Pinkston, and Donald E. Miser

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

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

Chemical, petrographic, and structural data on igneous rocks and associated ore deposits in the Christmas Mountains area reveal some similarities to the Sierra Blanca area. More than 70,000 tons of metallurgical-grade fluorspar were mined from lime-

J. G. Price

Bureau geologists Chris Henry and Jeff Rubin examine beryllium deposit underground in the Cyprus Beryllium Corporation test adit near Sierra Blanca.

stone-replacement orebodies on the margins of a rhyolite laccolith in the Christmas Mountains. Although locally anomalous in beryllium, the deposits do not appear to be consistently enriched, and no attempts have been made to extract beryllium. In contrast to the aluminous rhyolites at Sierra Blanca, the Christmas Mountains rhyolites are peralkaline and may have developed through different processes of differentiation and/or crustal melting.

A suite of late lavas that erupted 37 million years ago from the Infiernito caldera are being studied to understand processes leading to the evolution of high-silica rhyolites, with which many ore deposits are associated. Major-element, trace-element, and mineralogical analyses indicate that the magmas evolved from mafic trachyte through quartz trachyte and low-silica rhyolite to high-silica rhyolite, dominantly by a process of fractional crystallization but with measurable amounts of magma mixing and crustal assimilation.

Results of this research published this year include abstracts for national and regional meetings of the Geological Society of America and articles in a Geological Society of America Special Paper and in the *American Mineralogist*.

Regional Tectonic Stress with Time and Relation to Ore Deposits

Christopher D. Henry and Jonathan G. Price

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

An evaluation of sizes, orientations, and ages of epithermal gold-silver veins in the western United States

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

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

Research results were published this year as abstracts for the national and regional meetings of the Geological Society of America and for the North American Conference on Tectonic Control of Ore Deposits and the Vertical and Horizontal Extent of Ore Systems, and as a geologic map in the Geological Society of America Map and Chart Series. Funding was partly supplied by the Texas Mining and Mineral Resources Research Institute.

Texas Portland Cement Industry and Cement Resources

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

Texas was the second leading cement-producing state in the nation in 1986. A manuscript describing the industry of Texas and delineating geologic occurrence of current and potential resources, funded in part by the Texas Mining and Mineral Resources Research Institute, is in review for a Bureau publication.

The report is designed both to give the professional in the cement industry an appreciation of the vast supply of cement raw materials available in Texas and to acquaint the lay reader with an industry that produced products valued at $412 million in 1986.

Industrial Minerals

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

Texas is a leading state in the mining of industrial minerals. Most of the nearly $2 billion annual nonfuel mineral production comes from industrial minerals, chiefly cement, crushed stone, sand and gravel, and sulfur, but also includes significant quantities of salt, lime, industrial sand, clays, gypsum, dimension stone, and talc. Resources of some of these commodities are vast and easily accessible or, as in the case of sulfur, have values high enough that resources distant from markets can be exploited. Development of low-unit-value commodities, such as crushed stone and cement, depends heavily on transportation costs. Resources near major metropolitan areas are in some cases declining.

A manuscript on the Texas portland cement industry and the supply of cement raw materials is in review for publication by the Bureau. The Bureau also maintains a data base and provides computer printouts of nonpetroleum mineral producers in the state. Two new industrial minerals projects were initiated late in 1987: one on the dimension stone industry in Texas, including granite and limestone, and another on the Texas aggregate industry, including crushed stone and sand and gravel. These projects will include characterization and inventory of materials suitable for dimension stone, crushed stone, and sand and gravel resources. Funding for these projects is partly provided by the Texas Mining and Mineral Resources Research Institute.

The Bureau also cooperates with the U.S. Bureau of Mines by annually compiling and publishing data on the mineral industry of Texas in the Mineral Resource Circular series.

Texas Mining and Mineral Resources Research Institute

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, which is directed by Jonathan G. Price. 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 by non-Federal grants.

TMMRRI supports training and education of mining and mineral resource personnel through graduate fellowships, research assistantships, and undergraduate scholarships. The advisory board for TMMRRI is composed of the President of The University of Texas at Austin, the Vice-Chancellor and Dean of Engineering at Texas A&M University, and a member of the Railroad Commission of Texas. Representatives of the advisory board plus two members of the Texas mining industry serve on the TMMRRI Fellowship Committee. For the 1987–88 academic year three fellowships were awarded to support graduate research in geophysical aspects of rock mechanics and metallic ore deposits. In addition, four graduate students received support in

1987 through research assistantships on TMMRRI-funded mineral resource projects. These students are given the opportunity to participate in organized research that is often broader in scope than that for a dissertation or thesis.

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

Mapping Investigations

Geologic Atlas of Texas

Virgil E. Barnes, project director; Tucker F. Hentz and L. F. Brown, Jr.; Richard L. Dillon, Dan F. Scranton, and John T. Ames, cartographers

The 38th and final map in the Bureau's *Geologic Atlas of Texas*, the Wichita Falls-Lawton Sheet (Alfred Sherwood Romer Memorial Edition), was published in 1987. The entire state is now mapped at a scale of 1:250,000. The Geologic Atlas project has thus shifted from new mapping of 1-degree-latitude by 2-degree-longitude areas to revising out-of-print maps. Revisions are necessary because of new mapping that has been done by Bureau staff, graduate students, or non-Bureau researchers. The Dallas and Beeville-Bay City Sheets were revised and reprinted in 1987. The Sherman, Beaumont, and Abilene Sheets are in various stages of revision.

Geologic Map of Texas

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

A new 1:500,000-scale geologic map of Texas, largely derived from the *Geologic Atlas 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 nearly complete. 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), M. 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); David M. Ridner, cartographer.

This project, which will produce a full-color 1:750,000-scale tectonic map of Texas, incorporates 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.

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

Christopher D. Henry, Jonathan G. Price, and Donald E. Miser

Geologic mapping of these two quadrangles north of the Terlingua mercury district and Big Bend National Park was funded in part by the U.S. Geological Survey's

J. G. Price

Research Scientist Chris Henry examines top of 47-million-year-old basalt flow in the Hen Egg Mountain Quadrangle.

Cooperative Geologic Mapping Program (COGEOMAP). Detailed mapping of Tertiary dikes, sills, laccoliths, and volcanic rocks plus Cretaceous sedimentary rocks and Quaternary surficial deposits serves as a basis for future work on igneous petrogenesis and ore deposits in the area. These two quadrangles, which contain scattered silicic and mafic intrusions, include some of the more promising areas for mineral deposits in the Trans-Pecos region.

A major discovery during mapping was recognition of two small (approximately 4 km^2) but stratigraphically complex calderas in the Christmas Mountains. The calderas are unusual in that they are smaller, less silicic (quartz trachyte rather than rhyolite), and older (42 million years old, rather than 38 to 32 million years old, the age range of other calderas) than others in the Trans-Pecos magmatic province. The calderas were developed on the top of the elongate Christmas Mountains dome and may have resulted from ash-flow eruptions from a shallow laccolithic magma chamber. One of the calderas apparently reoccupied the vent of a basaltic volcano, remnants of which are seen in clasts in the volcanic rocks and in a semicircular outcrop of gabbro on the margin of the caldera.

Geologic Mapping in the Davis Mountains

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

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

Gravity and Magnetic Mapping of Texas

G. R. Keller (The University of Texas at El Paso, Department of Geological Sciences) and C. L. V. Aiken (The University of Texas at Dallas, Department of Geological Sciences), project directors; John T. Ames and Richard M. Platt, cartographers

Bouguer gravity and magnetic maps are being prepared to complement the 1:250,000-scale surface-geology maps of the *Geologic Atlas of Texas*. With the aid of computers, gravity data from many surveys are combined, reprocessed, and smoothed to a high-order polynomial surface. Magnetic maps are compiled from aeromagnetic data available from the National Uranium Resource Evaluation and from the U.S. Department of Defense. During 1987 progress was made toward completion of 10 one-by-two-degree magnetic maps of the Texas Panhandle for which gravity maps were published in 1986.

Other Geologic Investigations

Experimental Modeling of Salt Domes

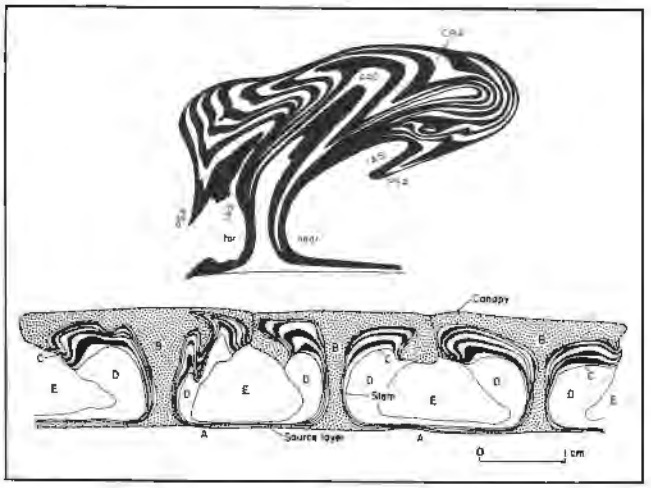
M. P. A. Jackson, project director; Reinold R. Cornelius, Claire H. Craig (The University of Texas at Austin, Institute for Geophysics), and Christopher J. Talbot (University of Uppsala, Sweden)

Research in 1987 was carried out with four different groups of salt diapir models to improve understanding of their kinematics and dynamics.

Results of centrifuge modeling during 1984 at the Hans Ramberg Tectonic Laboratory of the University of Uppsala were prepared for publication. These models simulated the growth of syndepositional diapirs under aggrading and prograding sediment loads, with emphasis on the evolving external shapes of the diapirs, including tonguelike diapirs moving sideways.

A related study dating from the same experimental period dealt with the origin and evolution of large-scale folds within mushroom-shaped diapirs. Such diapirs are fringed by skirts that enfold or entrain isoclinal folds or shredded screens of cover sediment within the diapir bulb. This geometry is significant to petroleum traps and to engineering within salt domes. The skirt can be coiled inwards to form a vortex. Some diapirs have several skirts, each of which may result from a pulse of sedimentation. Natural analogs to the centrifuge models are present in Germany, Iran, Canada, and the U.S. Gulf Coast. The results will be submitted for publication early in 1988.

Two centrifuged models in 1986 simulated the formation of salt canopies—large sheets of salt formed



Vertical sections of mushroom-shaped diapirs in centrifuged models. Top: a single diapir with a broad bulb fringed by hanging lobes. Bottom: part of a canopy in which the bulbs of several diapirs have fused laterally to form a composite structure. The stippled unit (B) represents the older salt and the striped unit the younger salt of the Great Kavir.

by the lateral spreading and fusion of adjacent diapir bulbs. Canopies, which represent the most mature type of diapirism, are present in central Iran and may also characterize the deep Gulf of Mexico. The model canopies evolved from initially circular diapirs that became polygonal through crowding before joining.

About 100 computer models using the analytical Rayleigh-Taylor theory were run at the Institute for Geophysics during 1987, mainly to explain the anomalously close spacing of the Great Kavir salt diapirs (described in the following article). The validity of this approach was confirmed by comparing the diapiric spacing predicted by linear analysis with the observed spacing in the 1986 centrifuged models. The models indicate that during syndepositional diapiric growth, the close spacing of diapirs beneath a thin cover can be preserved through later stages when the cover is thicker. Close spacing also requires that the viscosity contrast between buoyant source and cover be less than 10. In the case of Kavir diapirs, the immediate cover is a younger evaporite unit overlying the more buoyant, older evaporite. The clustering of diapirs can also be accounted for by thermal convection if the viscosity of both salt layers is less than 10^{16} Pa • s.

Great Kavir Salt Domes: A Generic Study of Diapiric Structure and Mechanics

M. P. A. Jackson, project director; Reinold R. Cornelius, Jovan Stöcklin (Seuzach, Switzerland), and Augusto Gansser (Swiss Federal Institute of Technology)

The Great Kavir in central Iran is the largest salt desert in that country. More than 50 Tertiary salt diapirs are exposed along its northern fringe in the foreland of the Elburz orogen. The Kavir diapirs are large, abundant, and superbly exposed, and they contain correlatable stratigraphy in the form of two distinctive evaporite units. These qualities provide an unrivaled opportunity for detailed analysis of diapir emplacement.

Results of the centrifuge and analytical modeling described in the previous article were integrated with remotely sensed data and field data collected in the Kavir during the 1950's and 1960's. The project has examined not only the internal structure of a wide range of salt intrusions but also the effects of superimposed regional folding and thrusting on diapiric emplacement. This research is in the final stages of writing.

The diapir province consists of 12 diapirs that have fused laterally to form a salt canopy, a less tightly spaced cluster of 12 discrete diapirs, and about 30 erratically spaced diapirs localized along regional faults and folds. Many of the exposed diapirs are actively rising, but only two have extruded salt glaciers, and these are only small flanges. All exposed diapirs are surrounded by a steep rim of gypsum cap rock.

Some of the Kavir diapirs have a simple domal structure, but most appear to be erosional sections through mushroom-shaped bulbs: a core of Eocene-Oligocene salt is separated from a synformal skirt of Eocene-Oligocene salt by a narrow infolded antiform of Oligocene-Miocene salt. All the structures in the Kavir diapirs, including coiled skirts and canopies, have been duplicated in the centrifuge experiments (see previous article).

Diapiric strain in the cover sediments is concentrated into a ductile shear zone around the diapir, suggesting that the cover deformed as a power-law (rather than Newtonian) viscous fluid. The superimposition of regional folding produced salt withdrawal basins of widely varying shape.

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

L. F. Brown, Jr., project director; assisted by Carl Fiduk

Analysis of Virgilian and Wolfcampian depositional sequences on the Eastern Shelf of the Midland Basin, an area covering approximately 22,000 mi^2 of North-Central Texas, continued in 1987. This project involves interpretation of depositional systems tracts within terrigenous clastic subsequences to reconstruct the paleogeography of 16 repetitive sequences containing hydrocarbons in this mature petroleum province.

Late in 1987, a report titled "Regional Stratigraphic Cross Sections, Upper Pennsylvanian and Lower Permian Strata (Virgilian and Wolfcampian Series), North-Central Texas," by L. F. Brown, Jr., Raul F. Solis Iriarte, and David A. Johns, was published by the Bureau. This report contains 23 regional cross sections encompassing a grid work of 2,000 mi.

During 1987, research focused on an attempt to identify and correlate marine condensed sections on the Eastern Shelf using gamma-ray logs. The purpose of this exercise was to see if this critical subsequence

boundary can be mapped in the subsurface. Results have been negative, suggesting that only the most anoxic highstand shales emit sufficient radiation to be identified and that considerable lateral variability exists in the shale facies.

A manuscript titled "Regional Depositional Systems and Paleogeography, Upper Pennsylvanian and Lower Permian, North-Central Texas" was in review in late 1987. It will include paleogeographic maps of 16 terrigenous clastic subsequences within the Virgilian and Wolfcampian Series in North-Central Texas. Cyclicity exhibited by the sequences is analyzed and presented using latest sequence concepts.

Depositional Framework and Genesis of Tertiary Submarine Gorges, Eocene, Northwest Gulf Coast

William E. Galloway, principal investigator; assisted by W. F. Dingus and R. E. Paige

Large erosional gorges cut into paralic sediments are prominent stratigraphic features of many depositionally active deltaic (offlap) continental margins. Increasingly, and without critical examination of the underlying premise, origin of such features is being equated with local or eustatic falls in sea level. The primary result of this proposed four-dimensional analysis of one family of Tertiary gorge fills is a critical reexamination of causal relationships between depositional setting, eustatic sea-level cycles, and local depositional or structural events and large-scale erosion at continental margins.

In 1987 three tasks were completed: (1) a description of three-dimensional geometry and stratigraphic setting of Eocene gorges on the Northwest Shelf of the Gulf Basin within the closely constrained framework of bounding depositional systems and contemporaneous structural growth, (2) the interpretation of the depositional architecture and origin of gorges and their fill, and (3) an assessment of the temporal relationship of gorge incision and filling to inferred worldwide eustatic cycles. Delineation of gorge morphology, syndepositional structural framework, paleogeographic setting, and position within Wilcox depositional cycles depended on analysis of well and geophysical data. Core and sample data from wells were used for age dating and lithologic interpretation of gorge fill and bounding facies.

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:

Baumgardner, R. W., Jr., and **Jackson, M. L. W.,** 1987, Landsat-based lineament analysis, East Texas Basin, and structural history of the Sabine Uplift area, East Texas and North Louisiana: The University of Texas at Austin, Bureau of Economic Geology, topical report prepared for the Gas Research Institute under contract no. 5082-211-0708, 117 p.

Caran, S. C., 1987, Stratigraphy of a playa-lake deposit within the proposed alignment of the Amarillo-area Superconducting Super Collider: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Texas National Research Laboratory Commission under contract no. IAC(86-87)-1708, 8 p.

Conti, R. D., and **Senger, R. K.,** 1987, Hydrostratigraphy of the Wolfcamp aquifer, Palo Duro Basin, Texas Panhandle: The University of Texas at Austin, Bureau of Economic Geology, topical report prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651, 44 p.

Dutton, S. P., 1987, Diagenesis and burial history of the Lower Cretaceous Travis Peak Formation, East Texas: controls on permeability in a tight gas sandstone: The University of Texas at Austin, Bureau of Economic Geology, topical report prepared for the Gas Research Institute under contract no. 5082-211-0708, 158 p.

Gustavson, T. C., ed., 1987, Geology and geohydrology of the Palo Duro Basin, Texas Panhandle, a report on the progress of nuclear waste isolation feasibility studies (1983): The University of Texas at Austin, Bureau of Economic Geology, annual report prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651, 382 p.

Hamlin, H. S., 1987, Hydrocarbon production and potential of the distal Frio Formation, Texas Coastal Zone and shelf: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Minerals Management Service under agreement no. 14-12-0001-30296, 84 p.

Hentz, T. F., Price, J. G., and **Gutierrez, G. N.,** 1987, Assessment of native sulfur potential of State-owned lands, Trans-Pecos Texas: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Texas General Land Office under contract no. IAC(86-87)-0787, 151 p. plus appendices.

Hovorka, S. D., 1987, Diagenesis of the San Andres Formation: unit 4 carbonate, G. Friemel and Detten wells: The University of Texas at Austin, Bureau of Economic Geology Open-File Report OF-WTWI-1985-41, Revision 1, final report prepared for the U.S Department of Energy, Salt Repository Project Office, under contract no. DE-AC97- 83WM46651, 71 p.

Kaiser, W. R., 1987, Cross-formational flow in the Palo Duro Basin, Texas Panhandle: The University of Texas at Austin, Bureau of Economic Geology Open-File Report OF-WTWI-1985-33, Revision 01, final report prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651, 39 p.

Kreitler, C. W., Raney, J. A., Mullican, W. F., III, Collins, E. W., and **Nativ, Ronit**, 1987, Geologic and hydrologic studies of sites HU1A and HU1B in Hudspeth County, Texas: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Low-Level Radioactive Waste Disposal Authority under contract no. IAC(86-87)-1061, 172 p.

Kreitler, C. W., Raney, J. A., Nativ, Ronit, Collins, E. W., Mullican, W. F., III, Gustavson, T. C., and **Henry, C. D.**, 1987, Siting a low-level radioactive waste disposal facility in Texas, volume four—geologic and hydrologic investigations of the State of Texas and University of Texas lands: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Low-Level Radioactive Waste Disposal Authority under contract no. IAC(86-87)-1722, 330 p.

Kreitler, C. W., Senger, R. K., and **Collins, E. W.**, 1987, Geology and hydrology of the northern segment of the Edwards aquifer with an emphasis on the recharge zone in the Georgetown, Texas, area: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Texas Water Development Board under contract no. IAC(86-87)-1046, 115 p.

Laubach, S. E., Baumgardner, R. W., Jr., and **Meador, K. J.**, 1987, Analysis of natural fractures and borehole ellipticity, Travis Peak Formation, East Texas: The University of Texas at Austin, Bureau of Economic Geology, topical report prepared for the Gas Research Institute under contract no. 5082-211-0708, 128 p.

Mukhopadhyay, P. K., 1987, Petrographic and chemical characterization of selected Texas Tertiary coals: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the U.S. Geological Survey, Branch of Coal Geology, under cooperative agreement no. 14-08-0001-A0399, 58 p.

Nance, H. S., 1987, The Artesia Group and Salado Formation (Guadalupian/Ochoan) of Palo Duro Basin: depositional systems and effects of post-Permian salt dissolution: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97- 83WM46651, 63 p.

Raney, J. A., Allen, P. M., Reaser, D. F., and **Collins, E. W.**, 1987, Geologic review of proposed Dallas-Ft. Worth area site for the Superconducting Super Collider (SSC): The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Texas National Research Laboratory Commission under contract no. IAC(86-87)-1708, 17 p.

Raney, J. A., Gustavson, T. C., and **Caran, S. C.**, 1987, Geologic review of proposed Amarillo area site for the Superconducting Super Collider (SSC): The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Texas National Research Laboratory Commission under contract no. IAC(86-87)-1708, 14 p.

Richter, B. C., Dutton, A. R., and **Kreitler, C. W.**, 1987, Sources of salt-water pollution in western Tom Green County: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Railroad Commission of Texas under contract no. IAC(86-87)-1003, 100 p.

Senger, R. K., 1987, Investigation of the possible effect of fracture zones on ground-water flow, Palo Duro Basin, West Texas: The University of Texas at Austin, Bureau of Economic Geology, interim report prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651, 56 p.

Senger, R. K., Conti, R. D., and Smith, D. A., 1987, Investigation of three-dimensional ground-water flow in the Deep-Basin Brine aquifer, Texas Panhandle: effects of lateral permeability variations: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651, 59 p.

Seni, S. J., Hamlin, H. S., and **Walter, T. G.**, 1987, Petroleum potential in Texas State submerged lands, Frio and Lower Miocene depositional episodes: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Texas General Land Office under contract no. IAC(86-87)-0797, variously paginated.

Tyler, Noel, Guevara, E. H., and **Coates, G. R.**, 1987, Geological characterization and reserve growth potential of Spraberry reservoirs in the Midland Basin, West Texas: The University of Texas at Austin, Bureau of Economic Geology, Reservoir Characterization Research Laboratory 1986-1987 annual report, 191 p.

Tyler, Noel, Light, M. P. R., and **Ambrose, W. A.**, 1987, Coordination of the geological and engineering research in support of the Gulf Coast co-production program: The University of Texas at Austin, Bureau of Economic Geology, annual report prepared for the Gas Research Institute under contract no. 5084-212-0924, 196 p.

White, W. A., and **Calnan, T. R.**, 1987, Colorado River Diversion Project, reconnaissance work to

establish monitoring stations in Matagorda Bay near the mouth of the Colorado River: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Texas Parks and Wildlife Department under contract no. IAC(86-87) 1756, 10 p.

The following Bureau publications served as final contract reports during 1987:

Baumgardner, R. W., Jr., 1987, Morphometric studies of subhumid and semiarid drainage basins, Texas Panhandle and northeastern New Mexico: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 163, 68 p.
Prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651.

Dutton, A. R., 1987, Hydrogeologic and hydrochemical properties of salt-dissolution zones, Palo Duro Basin, Texas Panhandle—preliminary assessment: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 87-2, 32 p.
Prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651.

Senger, R. K., Fogg, G. E., and **Kreitler, C. W.**, 1987, Effects of hydrostratigraphy and basin development on hydrodynamics of the Palo Duro Basin, Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 165, 48 p.
Prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651.

Simpkins, W. W., and **Gustavson, T. C.**, 1987, Erosion rates and processes in subhumid and semiarid climates, Texas Panhandle: statistical evaluation of field data: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 162, 54 p.
Prepared for the U.S. Department of Energy, Salt Repository Project Office, under contract no. DE-AC97-83WM46651.

White, W. A., Calnan, T. R., Morton, R. A., Kimble, R. S., Littleton, T. G., McGowen, J. H., and **Nance, H. S.**, 1987, Submerged lands of Texas, Beaumont-Port Arthur area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands: The University of Texas at Austin, Bureau of Economic Geology Special Publication, 110 p.
Financial assistance was provided in part by (1) the General Land Office of Texas, with funding in accordance with section 305 of the Coastal Zone Management Act for Coastal Zone Management Program (CZMP), (2) the Governor's Budget and Planning Office, with grants in accordance with section 308 of the same act for the Coastal Energy Impact Program (CEIP); CZMP and CEIP funding was administered by the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce, and (3) the Minerals Management Service of the U.S. Department of the Interior; parts of the study were conducted in cooperation with the U.S. Geological Survey. Contract numbers with the General Land Office were IAC(80-81)-1201, IAC(78-79)-1910, IAC(78-79)-0539, IAC(76-77)-1244, and IAC(76-77)-0833. Contract numbers with the Governor's Budget and Planning Office were CZ80M935019, IAC(80-81)-0865, and IAC(78-79)-1210. The contract number with the Minerals Management Service is 14-12-0001-30070.

Contract and Grant Support

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

Contract-management personnel prepare proposals and budgets, negotiate contracts, and monitor expenditures. During the contract period, technical and financial reports are distributed at monthly, quarterly, and annual intervals. In 1987, the following 40 contracts, each of which had reporting requirements, were active at the Bureau:

Federal

"Computerized Calculation and Characterization of Lignite Resources in Texas": supported by the U.S. Geological Survey, U.S. Department of the Interior.

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

"Depositional Framework and Genesis of Tertiary Submarine Gorges, Eocene, Northwest Gulf Coast": supported by the National Science Foundation.

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

"Geologic Mapping of the Christmas Mountains and Hen Egg Mountain 7.5-Minute Quadrangles, Christmas Mountains Intrusive Province, Trans-Pecos Texas": supported by the U.S. Geological Survey, U.S. Department of the Interior.

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

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

"Studies Related to Continental Margins (years 1 through 5)": supported by the Minerals Management Service, U.S. Department of the Interior (four contracts).

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

"Volcanic Centers in the Davis Mountains, Trans-Pecos Magmatic Province": supported by the U.S. Geological Survey, U.S. Department of the Interior.

State

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

"Assessment of the Hard-Mineral Resources Potential of State-Owned Lands": supported by the General Land Office of Texas.

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

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

"Colorado River Diversion Project—Reconnaissance Work": supported by the Texas Department of Parks and Wildlife.

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

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

"Geology and Ground-Water Hydrology of the Edwards Aquifer Recharge Zone, Williamson County, Texas": supported by the Texas Water Development Board.

"Preparation of a Petroleum Resource Data Base for Texas State Submerged Lands": supported by the General Land Office of Texas.

"Reconnaissance-Level, Hydrogeologic Investigation of the Feasibility of Siting a Low-Level Nuclear Waste Facility": supported by the Texas Low-Level Radioactive Waste Disposal Authority (four contracts).

"Sources of Salt-Water Pollution in Western Tom Green County": supported by the Railroad Commission of Texas.

Private

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

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

"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: Northwest Gulf of Mexico Continental Shelf": supported by Consolidated Natural Gas, Louisiana Land and Exploration, Mobil, Pennzoil, Standard Oil, Tenneco, and Texaco.

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

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

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

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

"Reservoir Characterization Research Laboratory": supported by ARCO, Exxon, Mobil, Standard Oil, and Texaco.

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 78-year history, the Bureau has published nearly 2,125 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 1.68 million publications have been distributed worldwide, mostly through direct sales. During 1987, about 23,000 volumes were distributed. The Bureau issued the following publications in 1987:

Special Publication

Submerged Lands of Texas, Beaumont-Port Arthur Area: Sediments, Geochemistry, Benthic Macroinvertebrates, and Associated Wetlands, *by W. A. White, T. R. Calnan, R. A. Morton, R. S. Kimble, T. G. Littleton, J. H. McGowen, and H. S. Nance. 110 p., 67 figs., 16 tables, 3 appendices, 6 plates ($12.50).*

Detailed inventory of submerged lands and associated wetlands in the Beaumont-Port Arthur area of the Texas Coastal Zone.

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

Reports of Investigations

RI 162. Erosion Rates and Processes in Subhumid and Semiarid Climates, Texas Panhandle: Statistical Evaluation of Field Data, *by W. W. Simpkins and T. C. Gustavson. 54 p., 40 figs., 18 tables, 1 plate ($3.50).*

Discussion and interpretation of erosion rate and climatic data recorded from 1978 through 1983 at six monitoring stations in actively eroding areas of the Texas Panhandle.

Bedded Permian salt in the Palo Duro Basin of the Texas Panhandle is under consideration by the U.S. Department of Energy for geologic disposal of high-level nuclear waste. Estimation of maximum erosion rates is necessary for determining the long-term integrity (10,000 years) of the repository structures and host rock. Since 1978 the Bureau has monitored, as part of a DOE-funded study, the rainfall amount and intensity, soil and air temperature, soil electrical resistance, slope erosion and deposition, and slope retreat in several different geomorphic environments within the Panhandle. Objectives were (1) to estimate present rates of slope erosion and deposition, (2) to estimate slope and stream headcut retreat in draws, in large playa lake basins, and along the margins of the Caprock Escarpment, and (3) to identify controls (such as rainfall intensity and slope angles) on those rates. The authors determined that slope erosion, slope retreat, and stream headcut retreat are occurring relatively rapidly and that precipitation intensity, slope vegetation, and soil texture significantly influence erosion and deposition in the study area.

RI 163. Morphometric Studies of Subhumid and Semiarid Drainage Basins, Texas Panhandle and Northeastern New Mexico, *by Robert W. Baumgardner, Jr. 68 p., 35 figs., 15 tables, 1 appendix ($3.00).*

Morphometric analysis of five drainage basins to determine the types and rates of geomorphic processes affecting the margins of the Southern High Plains.

Description and prediction of geomorphic processes are important for understanding the future of bedded salts beneath the Southern High Plains that are being considered as a repository for isolation of high-level nuclear waste. Stability of the repository will depend, in part, on the rate of retreat of the Caprock Escarpment and the interaction between surface denudation, scarp retreat, and salt dissolution. Predicting the future position of the Caprock Escarpment requires an understanding of the rates of geomorphic processes downstream from the escarpment. In this Department of Energy-funded study, the author used morphometric (shape) measurements to obtain a long-term, basinwide view of the geomorphic history of five drainage basins—Alamogordo Creek, Dixon Creek, Duck Creek, Little Red River, and McClellan Creek. Ruggedness number, relief ratio, drainage density, and hypsometric integral are the principal variables used to examine flooding potential, sediment export, and rates of scarp retreat and denudation.

RI 164. Diagenesis and Burial History of the Lower Cretaceous Travis Peak Formation, East Texas, *by Shirley P. Dutton. 58 p., 43 figs., 11 tables ($3.50).*

Investigation into the composition, geochemistry, burial and thermal history, and diagenetic history of the Lower Cretaceous Travis Peak Formation of East Texas.

The Travis Peak Formation produces substantial quantities of gas in the six-county study area, located on the western flank of the Sabine Uplift. However, extensive cementation has resulted in low permeability, requiring hydraulic fracture treatment for economic production. Understanding the diagenetic history of the formation can aid in predicting where the formation will be tight and in determining appropriate production methods. Using petrographic and geochemical techniques, the author identified detrital and authigenic phases in the formation, interpreted chemical and hydrologic conditions during cementation, integrated the diagenetic history with the burial and thermal history of the formation, and documented the effect of diagenesis on sandstone permeability. Results are discussed in the text, and figures and tables present detailed analytical results. The author concludes that porosity and permeability are most abundant in the upper Travis Peak and decrease with depth in the formation.

RI 165. Effects of Hydrostratigraphy and Basin Development on Hydrodynamics of the Palo Duro Basin, Texas, *by Rainer K. Senger, Graham E. Fogg, and Charles W. Kreitler. 48 p., 30 figs., 5 tables, 2 appendices ($3.00).*

Investigation into the effects of topography, hydrostratigraphy, and geologic processes on regional ground-water flow in the Palo Duro Basin of the Texas Panhandle.

The purpose of this study, funded by the U.S. Department of Energy, was to determine the suitability of the evaporite section of the basin as a repository for high-level nuclear waste. Predictions of the long-term behavior of a repository require detailed knowledge and understanding of ground-water hydrology surrounding the site. The authors used two-dimensional simulations of fluid flow in an east-west cross-sectional model to characterize regional ground-water flow, to investigate causes of underpressuring below the aquitard, and to evaluate mechanisms of recharge and discharge to and from the deep brine aquifers. Employing steady-state flow simulations, the authors investigated various effects of lithostratigraphy and topography on ground-water flow and used transient flow simulations to illustrate changes in regional hydrodynamics caused by different tectonic and geomorphologic processes. Modeling indicates that chief causes of underpressuring are the geology and the regional topography that was significantly affected by geomorphic processes within the last 1 to 2 million years.

RI 166. Origin and Evolution of Deep-Basin Brines, Palo Duro Basin, Texas, *by R. Stephen Fisher and Charles W. Kreitler. 33 p., 25 figs., 3 tables, 2 appendices ($3.00).*

Discussion of the composition, origin and evolution, and hydrodynamics of deep-basin brines in the Palo Duro Basin.

Porous and permeable strata of the Deep-Basin Brine aquifer underlie bedded evaporites that are being considered as a repository for high-level nuclear waste isolation. Detailed studies of the composition and movement of fluids in the Palo Duro Basin are critical to evaluating the suitability of this area for safe long-term isolation of nuclear wastes. In this Department of Energy-funded study, formation-water samples were collected from four DOE test wells and from two wells drilled by independent oil and gas companies. The samples were analyzed for chemical and isotopic compositions to characterize the geochemical environment,

determine the origin and compositional evolution of the water, and augment previous results of hydrologic investigations of ground-water flow directions and flow times. On the basis of their geochemical analyses, the authors discuss possible sources of water and compositional evolution paths, including connate evaporite brine; vertical, cross-formational recharge; and lateral recharge and rock-water interaction. The authors conclude that deep-basin formation waters are sodium chloride brines, that recharge is primarily lateral, and that cross-formational mass transfer is not a significant regional process.

RI 167. Landsat-Based Lineament Analysis, East Texas Basin and Sabine Uplift Area, *by Robert W. Baumgardner, Jr. 26 p., 18 figs., 5 tables ($2.50)*

Remote-sensing study of the relationship between subsurface structure and surficial features in East Texas, southeastern Oklahoma, southwestern Arkansas, and northwestern Louisiana.

Lineaments, linear features on the Earth's surface, may be spatially correlated with fractures in the subsurface, or they may reflect the regional stress regime. Determining such correlation can be useful in selecting drilling sites for hydraulic fracturing of low-permeability formations. In this Gas Research Institute-funded study, more than 2,200 lineaments were mapped from four standard 1:250,000-scale Landsat Thematic Mapper images; 83 percent of these were checked against photomosaics and described. The author reports that more than 90 percent of the described lineaments are stream network features; topographic features such as scarps account for only 2 percent of all described lineaments. Three types of correlations between lineaments and subsurface features are demonstrated: (1) high values of lineament density delineate major tectonic features, (2) trend of lineaments in the East Texas Basin is essentially parallel to the axes of elongated salt structures in the basin, and (3) vector sum of northwest-trending lineaments is exactly the same (325°) as the mean azimuth of wellbore elongations reported from 50 wells in the Jurassic Schuler Formation throughout East Texas. These results suggest that lineaments are manifestations of subsurface structure and that they developed as a result of the same stress regime that causes salt structures and wellbores to elongate.

RI 168. Characterization of the Grayburg Reservoir, University Lands Dune Field, Crane County, Texas, *by D. G. Bebout, F. Jerry Lucia, C. R. Hocott, G. E. Fogg, and G. W. Vander Stoep. 98 p., 85 figs., 9 tables, 4 color plates of photomicrographs ($6.50)*

Integrated geological and engineering study of the Grayburg reservoir in part of the Dune field, providing information essential for delineation of remaining oil within the reservoir and for implementation of more effective infill drilling and completion practices.

Methods described in this study, funded by The University of Texas System, are applicable to development of San Andres and Grayburg fields throughout the Permian Basin. The two reservoirs have yielded about 42 percent (9.8 billion barrels) of the total cumulative production of oil from the Permian Basin. Low recovery efficiencies have resulted in significant quantities of mobile oil remaining in the reservoirs after primary and secondary recovery. Cores from 17 wells provided the basis for the detailed geologic study of the facies, diagenesis, and porosity distribution and interpretation of depositional environments. Reservoir zones were delineated and mapped on the basis of knowledge of the geologic framework. Rock-fabric data and mineralogy were integrated with wireline response in order to transform transit-time and resistivity data into estimates of porosity, permeability, and water saturation. Using these data, the authors formulated zonal maps of mobile oil, identifying 10.2 million barrels of remaining oil as of 1987 in an area of only 1 square mile.

Geological Circulars

GC 87-1. Historical Shoreline Changes in San Antonio, Espiritu Santo, and Mesquite Bays, Texas Gulf Coast, *by William A. White and Robert A. Morton. 41 p., 31 figs., 1 table, 3 appendices ($2.50).*

Documentation of extensive shoreline changes within the San Antonio Bay system since the 1850's and discussion of the physical processes that cause shoreline movement.

Observed long-term changes in shoreline position provide estimates of the relative stability of shorelines and allow comparisons of shoreline changes before and after human modifications became significant. Analysis of shoreline movement in the San Antonio Bay system included comparing topographic charts (dated 1857 to 1860) with aerial photographs (taken between 1929 and 1937 and in 1957, 1974, and 1982), measuring shoreline movement, calculating the rates of change for particular time periods (late 1800's to 1930's, 1930's to 1982, and

late 1800's to 1982), and summarizing in tables and on maps the magnitude and rates of shoreline change. The authors report that, despite the local use of shoreline protection measures, approximately 70 percent of the shorelines within the San Antonio Bay system retreated at net rates of between 0.2 and 11 ft/yr between the late 1850's and 1982. They predict that unprotected shorelines in the system will continue to retreat in response to natural erosional conditions that have been augmented by human activities.

GC 87-2. Hydrogeologic and Hydrochemical Properties of Salt-Dissolution Zones, Palo Duro Basin, Texas Panhandle—Preliminary Assessment, *by Alan R. Dutton. 32 p., 16 figs., 6 tables, 1 appendix ($2.00).*

Characterization of the hydrology of salt-dissolution zones in and around the Palo Duro Basin and investigation into the timing, rate, and mechanism of salt dissolution.

Permian bedded salt beneath the northern part of the Southern High Plains in the Texas Panhandle is being considered for use as a geologic repository of high-level nuclear waste. Long-term stability of salt deposits is a major geotechnical and hydrogeologic concern in repository siting. Sinkholes and other evidence indicate that salt dissolution is an active, dynamic hydrogeologic process in the area. In this Department of Energy-funded study, data were collected from six test wells: four were drilled for hydrologic testing and geochemical sampling of salt-dissolution zones in the Panhandle, and drill-stem tests at the two other wells were conducted to measure permeability and hydraulic head. Chemical composition of ground waters sampled from two test wells along the perimeter of the Southern High Plains clearly reflects dissolution of halite, gypsum, calcite, and dolomite by circulating ground water. Halite dissolution accounts for most of the salinity of Na-Cl ground water in salt-dissolution zones. At present, ground water in salt-dissolution zones is undersaturated with respect to halite. Presence of ^{14}C in the ground water and the large concentration of dissolved solids discharging into streams draining the area indicate that the salt-dissolution process has taken place throughout the Holocene and is ongoing.

GC 87-3. A Saponite and Chlorite-Rich Clay Assemblage in Permian Evaporite and Red-Bed Strata, Palo Duro Basin, Texas Panhandle, *by David P. Palmer. 21 p., 13 figs., 5 tables, 1 appendix ($1.50).*

Description of magnesium-enriched mixed-layer expandable clays, their origin and chemistry, and the probable mechanism for diagenetic modification of clays in the Palo Duro Basin, Texas Panhandle.

Bedded salt deposits in the Palo Duro Basin are being evaluated as a possible repository site for nuclear waste, and clay mineral type, location, and abundance are integral parts of the host rock suitability analysis. In particular, expandable clay materials must be identified prior to repository siting and design because their swelling properties may affect the structural stability of the repository. In this Department of Energy-funded project, the author describes lithology of core samples from two Department of Energy wells in Randall and Swisher Counties and determines clay mineralogy and X-ray diffraction response using 73 samples from the Randall County well and 40 samples from the Swisher County well. On the basis of his analyses, the author identifies the clay assemblage in the Palo Duro Basin evaporites as consisting of saponite, a magnesium-rich smectite; mixed-layer chlorite/smectite; chlorite/vermiculite; chlorite/swelling chlorite; vermiculite/swelling chlorite; chlorite; and illite. Chemical analyses reveal that the chemical composition of the mixed-layer clays is intermediate between normal aluminum-rich detrital clays and normal vermiculite and chlorite, magnesium clays of hydrothermal or metamorphic origin. The author postulates that rates and amounts of clay alteration are probably controlled by magnesium ion activity, brine salinity, brine pH, and sediment and clay residence time in the marine evaporite environment.

GC 87-4. Can the U.S. Oil and Gas Resource Base Support Sustained Production? *by William L. Fisher. 6 p., 6 figs. ($1.00).*

Article by the Bureau's Director, reprinted from Science, investigating whether the U.S. is capable of sustaining production from its ample, though marginal, resource base and whether it is in the national interest to encourage such production.

The author notes that the U.S. is a maturely explored and developed oil and gas province, but that aggressive drilling in the lower 48 states in the past decade resulted in reserve additions sufficient to arrest decline and to stabilize levels of production. The author states that the remaining resources of oil and gas in the U.S. are substantial. Exploration of new fields at current rates of finding can be pursued at the levels of the past few years for at least 30 more years. Reserve growth from conventional but geologically targeted development techniques can maintain recent production-stabilizing levels of additions for 25 years, with half the remaining volumes recovered. Advanced tertiary techniques, if pursued to the extent that one-fourth of remaining residual and heavy oil volumes could be recovered, would support 1985 levels of production of the lower 48 states for an additional 20 years. In all, Fisher states, the U.S. oil resource base seems capable of providing stable production in the lower 48 states for the next 50 years.

GC 87-5. Rock Fabric, Permeability, and Log Relationships in an Upward-Shoaling, Vuggy Carbonate Sequence, *by F. Jerry Lucia and Robert D. Conti. 22 p., 26 figs., 4 tables, 4 appendices ($2.00).*

Explanation and application of a new method for calculating permeability in carbonate rocks using wireline log responses.

Total porosity can be determined from neutron, acoustic, and density logs, but the distinction made between interparticle and separate-vug porosity using log responses has never been quantifiable. As a result, such a rock-fabric distinction has never been integrated into permeability estimates drawn from log analysis. The distinction is important because only interparticle porosity contributes to permeability. Cores and logs used in the study were from a Department of Energy well in Oldham County containing a wide range of separate-vug porosity in a simple upward-shoaling carbonate sequence of early Permian (Wolfcampian) age. The authors investigated two wireline methods, one involving acoustic logs and one involving resistivity logs, and both were found to determine separate-vug porosity. Two equations relating interparticle porosity and permeability were derived using the general relationship between particle size, interparticle porosity, and permeability described earlier by Lucia as a guide to define porosity-permeability relationships. The authors report that permeabilities calculated using particle-size and interparticle porosity determined by subtracting separate-vug porosity from total porosity are more accurate than those calculated from total porosity data alone. In addition, the rock-fabric method reproduces the core permeability profile, revealing the high-porosity, low-permeability oomoldic zone, whereas the standard method does not.

Cross Sections

Regional Stratigraphic Cross Sections, Upper Pennsylvanian and Lower Permian Strata (Virgilian and Wolfcampian Series), North-Central Texas, *by L. F. Brown, Jr., Raul F. Solis Iriarte, and David A. Johns. 27 p., 9 figs., 1 table, 1 appendix on microfiche, 27 plates ($12.00).*

Fourteen dip (E-W) sections and nine strike (N-S) stratigraphic cross sections (with text), correlating upper Pennsylvanian (Virgilian) and lower Permian (Wolfcampian) strata throughout the subsurface in all or parts of 28 counties of North-Central Texas.

The cross-section network covers 22,000 square miles and was constructed by combining outcrop data with electric log data from 1,185 wells along 2,000 miles of cross sections to correlate about 20 limestone units. The network was further verified by correlating the limestones on electric logs from 4,000 additional off-section wells for a total of more than 5,100 control points. Cores and samples were used locally to calibrate the lithic interpretation of electric logs. The cross sections define 16 principal and several lesser lithogenetic units, delineate many tectonic and paleobathymetric elements, and permit the distinction of four major depositional phases during the Virgilian and Wolfcampian Epochs. Published at a horizontal scale of approximately 6 miles per inch and a vertical scale of 200 feet per inch, the sections are designed to (1) provide regional correlations and stratigraphic control for geologists involved in subsurface studies of the Eastern Shelf and adjacent Midland Basin; (2) establish a regional stratigraphic framework necessary to map the distribution of sandstone bodies within the major lithostratigraphic units; (3) equate stratigraphic nomenclature established at type localities in outcrop with informal subsurface names used by petroleum geologists; (4) demonstrate the vertical and lateral variations in the principal Virgilian and Wolfcampian depositional sequences; and (5) provide a regional lithostratigraphic reference framework for workers who wish to unify petrographic, geochemical, paleontologic, and other geological data.

Mineral Resource Circular

MRC 79. The Mineral Industry of Texas in 1985, *by J. P. Ohl and M. W. McBride. 20 p., 2 figs., 12 tables (free on request).*

Annual summary of all nonfuel minerals of Texas.

This circular is a preprint of the chapter on Texas in the *Minerals Yearbook 1985* 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.

Maps

Geologic Atlas of Texas, Wichita Falls - Lawton Sheet, Alfred Sherwood Romer Memorial Edition, *by T. F. Hentz and L. F. Brown, Jr.; V. E. Barnes, project director ($4.00).*

Geologic map sheet covering all of Archer, Wichita, Wilbarger, Hardeman, Baylor, and Knox Counties and most of Jack, Young, Throckmorton, Haskell, Foard, and Clay Counties.

The Wichita Falls - Lawton Sheet is the last sheet of the Bureau's Geologic Atlas of Texas, a series of 38 map sheets showing the distribution of outcropping rock units in all of Texas and parts of adjacent states. The map was reviewed by the North Texas Geological Society and is printed in full color on a topographic base at a scale of 1:250,000. This sheet is a memorial edition honoring Alfred Sherwood Romer (1894–1973). Dr. Romer, a vertebrate paleontologist of international renown, first visited North-Central Texas in 1926 as part of an expedition to collect fossil reptiles and amphibians from the Permian red beds. As a professor of vertebrate paleontology at the University of Chicago and later as the Alexander Agassiz Professor of Zoology at Harvard University, Dr. Romer made many subsequent field trips to the area and published numerous scientific articles concerning the morphology and evolution of these classic continental faunas.

Miscellaneous Map No. 37. Structure-Contour Map on the Lower Permian Red Cave Formation, Panhandle Field and Adjacent Areas of the Texas Panhandle, *by R. T. Budnik. 8 p., 3 figs., 1 appendix, 3 plates ($2.00).*

Structure-contour map on top of the Red Cave Formation, encompassing Hartley, Oldham, Potter, Moore, Hutchinson, Carson, Gray, Wheeler, and Collingsworth Counties in the Texas Panhandle.

The map is accompanied by an east-west cross section, a north-south cross section, and a short text that present information on the post-Pennsylvanian deformation of the Amarillo Uplift and the structure within the Panhandle field. Funding was by the Department of Energy.

Services

Core Research Center

The Core Research Center (CRC) and adjacent repository are open from 8:00 a.m. to 5:00 p.m. Monday through Friday. Information about holdings, policies, and computer listings may be obtained by calling Allan R. Standen, Curator, at (512) 471-1534, extension 400. A brochure describing the CRC is available upon request.

Approximately 5,600 cores and 46,000 well cuttings may be checked out from the CRC for study on site or for use outside the Bureau. Samples may be borrowed for 6 weeks; extensions are considered. Taking samples or thin sections from cores or cuttings requires approval by the curator, and patrons are requested to provide results of analyses to the CRC, which then become part of the center's reference material. The CRC has viewing, thin section, slabbing, photographic, radiographic, and gamma-scan facilities available to the public.

During 1987 the CRC was visited by more than 300 non-Bureau patrons, who examined more than 5,000 boxes of cores and cuttings. The CRC staff slabbed and reboxed cores totaling 18,000 linear feet from more than 250 wells. The thin section lab produced more than 1,900 thin sections. The photography section, which photographs cores and hand samples, produced more than 1,500 photographs in 1987. New acquisitions of core and cuttings in 1987 totaled more than 25,000 boxes, or more than 200,000 linear feet. Companies donating core this year were Anschutz Oil Company; Apache Corporation; ARCO; Bracken Energy; Celeron Oil Company; D. K. Davies and Associates; Eastland Oil Company; Exxon; Gunn Oil; Hanson Oil; Holditch and Associates; Hunt Energy; Indian Wells; Inexco; Ladd Petroleum; Laughlin Air Force Base; London Petroleum; Louisiana Land and Exploration; McCellan Associates; McLelland Consultants; McMoran Exploration; Pan Canadian Petroleum Company; Pennzoil Oil; Phillips Oil; Reservoirs, Inc.; R.P.I.; Texas Water Commission; U.S. Bureau of Mines; and U.S. Gypsum.

Mineral Studies Laboratory

The Mineral Studies Laboratory (MSL), comprising 18,500 ft^2 of laboratory space and a staff of eight analytical chemists and geochemists, is capable of near-complete geochemical characterization of geological materials. Major analytical instruments available include an ARL 35000 inductively coupled plasma optical emission spectrometer, a VG PlasmaQuad inductively coupled plasma mass spectrometer, a VG SIRA 12 stable isotope mass spectrometer, a Cameca Camebax electron microprobe, a Jeol SEM/EDXRF microscope, a Dionex 2001 ion chromatograph, and a Phillips X-ray diffractometer. Complete wet chemical analysis, coal analysis, sample comminution, and fire assay capabilities also exist. These services are available to the Texas geological community but are primarily applied in Bureau research programs. The MSL is directed by Chief Chemist David W. Koppenaal.

Primary technical activities of the MSL in 1987 included various geochemical characterization efforts for Bureau research projects. Geochemical research activities at the MSL focused on developing a helium inductively coupled plasma/mass spectrometry (ICP-MS) technique (first demonstrated at the MSL) for determination of halogens in halites and brines, searching for a more sensitive and accurate technique for determination of water in rocks and minerals, and applying the ICP-MS technique to geological materials analysis and characterization.

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 participates in the work of several committees of the American Society for Testing and Materials, including subcommittees on Coal and Coke, Hazardous Wastes, and Water.

During 1987 several new analytical capabilities were added to the MSL. The installation and implementation of a stable-isotope geochemistry laboratory were completed, enabling determination of natural isotope abundances of carbon and oxygen in carbonates and hydrogen and oxygen in waters and brines. A fire-assay laboratory for determination of precious metals was also completed. Rare-earth element (REE) analyses by ICP-MS were perfected, and a new gas chromatograph was obtained. Additional instrumental improvements to the ICP-MS were made, bringing this powerful instrument capability into more routine use. A Class-100 clean-air hood was obtained and installed for ultra-trace REE determination needs and for preparation of Bureau samples for isotopic analysis using the Department of Geological Sciences' new thermal ionization mass spectrometer.

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 organiza-

tions. Extensive data and information are available at the Bureau's Reading Room/Data Center, and members of the Bureau's research staff provide advisory and technical services in their areas of expertise. The Public Information Geologist, Mary W. McBride, maintains files on mineral resources and general geology of specific areas of Texas and assists patrons in locating answers to specific questions. During 1987, approximately 1,500 requests for information were handled by the 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 Reading Room/Data Center, supervised by Jeffrey Thurwachter, 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 13,000 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. Arrangements can be made to photocopy noncopyrighted materials.

The Data Center houses an extensive collection of surface and subsurface geologic data pertaining to Texas and adjacent states. Research Document Inventory (RDI) 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, Texas air photos, and Landsat images also are available. Subsurface data files include well logs for more than 50,000 wells in Texas and 8,000 wells in adjacent states; microfiche copies of well logs for more than 40,000 wells in West Texas, New Mexico, and Oklahoma; scout tickets and well records for more than 200,000 Texas wells and 30,000 New Mexico wells; driller's logs for about 400,000 Texas wells; and more than 300,000 completion cards for Texas wells and more than 150,000 completion cards for wells in adjacent states.

New acquisitions of the Reading Room/Data Center in 1987 included more than 800 monographs and serials, 270 maps, 4,000 well logs, and 15,000 well completion cards. In 1987, Reading Room staff cataloged, indexed, and entered into a computer data base more than 2,200 items, including 1,300 serials and monographs from the W. Armstrong Price collection. In addition, more than 500 journal volumes, including over 2,200 journal issues from the Price collection, were cataloged and added to the Reading Room holdings. Another 1987 accomplishment was implementation of a computer data base to track the more than 450 books and journals circulated each month.

Geophysical Log Facility

The Bureau's Geophysical Log Facility (GLF) 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 provides paper or microfiche copies of the well logs and three different cumulative indexes to these logs. The logs are filed at the GLF by district number and by API number. 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.

During 1987 the facility received 7,863 well logs, bringing the total number of logs held to about 29,000. Early in the year a computer data base was designed and implemented to track the log type, number of logs, and number of fiche received at the GLF; this data base currently contains more than 10,000 records.

The Geophysical Log Facility is managed by Jeffrey Thurwachter and operated by Pat Downs. Hours of operation are 8:30 a.m. to 4:30 p.m. Monday through Friday. The GLF is housed in the Reading Room/Data Center, located in the Bureau's Research and Administration Building at Balcones Research Center. The telephone number is (512) 471-1534, extension 141.

Highlights of the Year

Bingler Strives to Bring SSC to Texas

Edward C. Bingler, Deputy Director of the Bureau, accepted a temporary assignment early in the year to serve as Executive Director of the Texas National Research Laboratory Commission. Robert J. Finley has served as Acting Deputy Director during his absence. Bingler's primary responsibilities with the Commission were to prepare a proposal to the Department of Energy for siting a Superconducting Super Collider in Texas and to strive to secure acceptance of the proposal. The SSC would be a multibillion dollar project for the state. The Commission submitted two separate proposals to DOE in August: one for a Dallas–Ft. Worth site and the other for an Amarillo site. At the end of the year the Dallas–Ft. Worth site was named one of eight finalists in the site selection process. The SSC site is expected to be announced in July 1988 and confirmed in January 1989.

Through an interagency contract the Bureau assisted in the preparation of documents in support of the SSC proposals. Bureau scientists who contributed geologic and hydrologic data included L. F. Brown, Jr., S. Christopher Caran, Edward W. Collins, Thomas C. Gustavson, Charles W. Kreitler, H. Seay Nance, and Jay Raney.

Milling Joins Senior Staff

Marcus Milling was named Program Director of the Bureau's High-Level Radioactive Waste Isolation program. Most recently Milling was Manager Geological Staff and Chief Geologist at ARCO in Dallas. Previously he was Manager Geological Research at ARCO and a researcher and district geologist at Exxon. Originally from Galveston, Milling has a Ph.D. in geology from the University of Iowa. He is a member of the American Association of Petroleum Geologists, Geological Society of America, Society of Exploration Geophysicists, Society of Petroleum Engineers, Houston Geological Society, American Institute of Professional Geologists, and Austin Geological Society.

New Research Staff Members

William Ambrose

William Ambrose joined the Bureau in January as a Research Scientist Associate on the gas atlas and reserves growth projects. Ambrose had been a Research Assistant at the Bureau from 1982 to 1984. Originally from Kentucky, Ambrose has a master's degree in geology from The University of Texas at Austin. Before rejoining the Bureau, Ambrose was a research geologist with the Research Planning Institute of Texas, Austin. He is a member of the American Association of Petroleum Geologists and Austin Geological Society.

Regina Capuano

Regina Capuano joined the Bureau in August as a Research Associate on the EPA-funded project concerning deep-well injection of chemical wastes. Capuano has a Ph.D. in geosciences from the University of Arizona. Her dissertation topic was chemical equilibria and fluid flow during compaction diagenesis of organic-rich geopressured sediments. Prior to her graduate studies, Capuano was a geochemist/project manager at the University of Utah Research Institute. She is a member of the American Association of Petroleum Geologists, American Geophysical Union, and Geochemical Society.

Stephen J. Martel

Stephen J. Martel joined the West Texas Waste Isolation project in August as a Research Associate. Originally from upstate New York, Martel received a Ph.D. from Stanford University in geomechanics. His dissertation concerned development of strike-slip fault zones in granitic rock, Mount Abbott Quadrangle, Sierra Nevada, California. He is a member of the Geological Society of America and American Geophysical Union.

Bridget Scanlon

Bridget Scanlon joined the Bureau in June as a Research Associate on a project funded by the Governor's Nuclear Waste Programs Office. A native of Ireland, Scanlon received a Ph.D. in geology from the University of Kentucky at Lexington. Her dissertation concerned chemical, physical, and microbiological characteristics of ground water in the Inner Bluegrass Karst Region of central Kentucky. Before joining the Bureau Scanlon was a hydrogeologist with S. S. Papadopulos and Associates in Rockville, Maryland. She is a member of the American Geophysical Union, International Association of Hydrologists, and National Water Well Association.

James A. Morgan

Researchers (clockwise from top left) Regina Capuano, William Ambrose, Robert Tye, Bridget Scanlon, and Stephen Martel joined the Bureau staff in 1987.

Robert Tye

Robert Tye joined the Bureau in June as a Research Associate on the Low-Permeability Gas Sandstone Reservoirs project. Originally from South Carolina, Tye has a Ph.D. in marine sciences from Louisiana State University at Baton Rouge. His dissertation topic concerned stratigraphy and sedimentology of lacustrine deltas. Before joining the Bureau Tye was a research associate at LSU and a reservoir geologist with Cities Service Company in Tulsa. He is a member of the International Association of Sedimentologists, Society of Economic Paleontologists and Mineralogists, and Austin Geological Society.

Promotions

Martin P. A. Jackson

Martin P. A. Jackson, who has been with the Bureau since 1980, was promoted to Senior Research Scientist. Jackson works on the West Texas Waste Isolation project. His research on the tectonics of salt deformation has received international recognition. Jackson is currently completing research on the salt domes of the Great Kavir, Iran.

Robert A. Morton

Robert A. Morton was promoted to Senior Research Scientist; he has been with the Bureau since 1972. Morton supervises the industry-sponsored research project investigating offshore Texas oil and gas resources. His work on modern coastal sediments has received worldwide attention. Morton currently analyzes the stratigraphy and sedimentology of Holocene strata on the Texas outer shelf and slope, Gulf of Mexico Basin.

Alan R. Dutton

Alan R. Dutton, who has been with the Bureau since 1982, was promoted to Research Scientist. Dutton works on the West Texas Waste Isolation project as a principal investigator for hydrological studies. Dutton's current research concerns paleohydrology related to geomorphologic evolution of the Southern High Plains, hydrogeology of salt-dissolution zones and brine discharge areas in the Texas Panhandle and Rolling Plains, and geochemistry of formation brines in the Permian Basin.

Shirley P. Dutton

Shirley P. Dutton, who has been with the Bureau since 1977, was promoted to Research Scientist. She is Acting Program Director of the Gas Resources program. Dutton's current research involves the depositional and diagenetic history of Travis Peak sandstones and their relationship to gas production and the relationship between mineral diagenesis and permeability distribution in the Travis Peak Formation.

Robert W. Baumgardner, Jr.

Robert W. Baumgardner, Jr., was promoted to Research Associate. He has been with the Bureau since 1979 and currently works on the Low-Permeability Gas Sandstone Reservoirs project. Baumgardner uses remote sensing data and borehole data to analyze in situ stress in order to relate fracture orientations to gas production from extremely low porosity sandstones.

James A. Morgan

Researchers (clockwise from top left) Martin Jackson, Robert Morton, Shirley Dutton, Robert Baumgardner, and Alan Dutton received promotions during 1987.

University Lands Colloquium

Scientists working on the University Lands project presented a review of their research at a colloquium in Midland in April. Approximately 160 people, mostly from industry, attended the meeting, which was jointly organized by the Bureau and The University of Texas System. Bureau Director William L. Fisher presented the rationale for reserve growth on University Lands, and field-specific presentations were given by Don Bebout, Graham E. Fogg, Edgar Guevara, Claude Hocott, Charles Kerans, F. Jerry Lucia, R. P. Major, and Stephen C. Ruppel. Noel Tyler closed the meeting with a review of University Lands research in the context of the Greater Permian Basin.

Bureau Co-Hosts Continental Margins Symposium

The Bureau, the Minerals Management Service, and the Continental Margins Committee of the Association of American State Geologists sponsored a symposium in November at Balcones Research Center, The University of Texas at Austin, on "Studies Related to Continental Margins." Fifty-six people from 19 states participated in the meeting. Papers were presented by representatives from states under contract to the Minerals Management Service to conduct research on geologic framework, petroleum resources, and strategic minerals associated with continental margins.

Bureau Director William L. Fisher welcomed the group to Austin. Charles G. Groat, president of the Association of American State Geologists, State Geologist of Louisiana, and former associate director and acting director of the Bureau of Economic Geology, spoke at the opening session. John B. Rigg, Associate Director for Offshore Minerals Management, Minerals Management Service, Washington, D.C., delivered the keynote address.

The symposium was organized by Associate Director for Administration Douglas C. Ratcliff. Bureau staff provided logistical support and computing and shuttle bus services. Charles Kerans and Stephen C. Ruppel conducted a field trip to the Llano area as part of the symposium.

Bureau Staff Participate in SEPM Meeting

Bureau staff did much to make the 1987 Society of Economic Paleontologists and Mineralogists midyear meeting in Austin a success. The meeting, held in August, featured the theme "Forward into the Past." Robert A. Morton was general chairman, and programs and committees were headed by Don Bebout, Shirley P. Dutton, R. Stephen Fisher, Michael A. Fracasso, Charles Kerans, Mary W. McBride, Douglas C. Ratcliff, Stephen C. Ruppel, and Noel Tyler.

In all, Bureau researchers presented 14 papers, 3 field trips, 2 poster sessions, and 2 core workshops. Bureau staff also chaired technical sessions, served as judges, and assisted on committees.

Awards and Honors

Hartmann Receives UT Excellence Award, Merit Certificate

Senior Cartographer Barbara Hartmann received the prestigious UT Excellence Award in May. The awards are given annually to about 50 UT staff members who exhibit "consistent, high-level" performance. Hartmann received a $500 check and the personal congratulations of President William H. Cunningham at the 26th Annual Staff Recognition Program and President's Reception.

James A. Morgan

Barbara Hartmann shows Submerged Lands project principal investigator Bill White the certificate of merit she was awarded for her work on the Brownsville-Harlingen area wetlands map.

Hartmann, originally from Hamburg, West Germany, joined the Bureau in 1957. She has been with the Bureau for 23 years, having taken off some time to raise two children. Hartmann has worked on several major mapping projects at the Bureau, including the "Energy Resources of Texas" map, the "Mineral Resources of Texas" map, the "Atlas of Major Texas Oil Reservoirs," six *Geologic Atlas of Texas* sheets, three maps for the *Environmental Geologic Atlas of the Texas Coastal Zone,* and two quadrants of the "Land Resources of Texas" map. Hartmann is currently primarily responsible for color mapping, including work on the *Submerged Lands of Texas* atlases during the last 4 years. In 1987 she was also awarded a certificate of merit for the Brownsville-Harlingen area Submerged Lands map in a design contest sponsored by the American Congress on Surveying and Mapping in cooperation with the American Cartographic Association. Hartmann's award was for "Best in Category—Series Maps and Charts, 1986."

Bureau Director William L. Fisher described Hartmann as "the epitome of the dedicated and talented Bureau staffer, the kind of person that gives us the fine reputation we enjoy." Senior Administrative Clerk James Doss won the UT Excellence Award in 1986.

Bureau Staff Receive Service Awards

Eight Bureau staff members with 10 and 15 years of service to the University were among those honored at the 26th Annual Staff Recognition Program and President's Reception in May. The staff members were also congratulated by Director William L. Fisher during an awards ceremony at the Bureau. Honored for 15 years of service were Executive Assistant Bettye

Blitch, Senior Research Scientist Robert A. Morton, and Associate Director for Operations and Assistant to the Director E. G. Wermund, Jr.; honored for 10 years of service were Research Associate Robert W. Baumgardner, Jr., Research Scientists Don Bebout and Shirley P. Dutton, Designer Margaret L. Evans, and Senior Administrative Associate Wanda LaPlante.

Research Staff Receive Awards for Papers, Poster Sessions

Shirley P. Dutton, Robert J. Finley, and Karen Herrington won the First Place Best Paper Award at the 37th Annual Gulf Coast Association of Geological Societies meeting in San Antonio. Dutton presented the paper, titled "Organic Geochemistry of the Lower Cretaceous Travis Peak Formation, East Texas Basin."

Elisabeth C. Kosters, along with two co-authors, was awarded the 1986 Best Paper Award by the Geological Society of America. The paper, co-authored by G. L. Chmura and R. E. Ferrell, concerned mineralogical characteristics of an underclay in the Barataria Basin of the Mississippi River Delta. Kosters also received the 1987 Society of Economic Paleontologists and Mineralogists Excellence of Presentation Award for her poster session presented at the AAPG-SEPM annual meeting in Los Angeles. The session, co-authored by Shea Penland and John Suter, was titled "New Depositional Model for the Mississippi Delta Plain."

William E. Galloway was awarded third place for a poster session presented at the SEPM midyear meeting. The session, co-authored by S. A. Reynolds, was titled "Depositional Systems and Fluvial Architecture of the Narabeen Group, Sydney Basin, Australia."

Charles W. Kreitler was awarded Outstanding Poster Presentation in the category of empirical research at the Texas Public Health Association annual meeting in Ft. Worth. The poster session, titled "Sources and Distribution of Radium-226 and Radon-222 in Domestic Water in Harris County, Texas," was co-authored by Irene Cech of the UT Health Science Center in Houston.

Bebout Named SEPM Honorary Member

Senior Research Scientist Don Bebout was named an honorary member of the Gulf Coast Section of the Society of Economic Paleontologists and Mineralogists at the Gulf Coast Association of Geological Societies annual meeting in San Antonio. GCAGS cited Bebout's contributions to carbonate petrology through writings, core workshops, and field trips. Bebout served as President of the Gulf Coast Section of SEPM from 1983 to 1984 and is currently a Foundation Trustee.

Barnes Named AAAS Fellow

Senior Research Scientist Virgil E. Barnes, known internationally for his research on tektites, was elected a Fellow of the American Association for the Advancement of Science at the group's annual meeting in Chicago. A Fellow of the Association is described as "a member whose efforts on behalf of the advancement of science or its applications are scientifically or socially distinguished." The AAAS, which publishes the weekly journal *Science*, is the leading scientific organization in the United States. Formed in 1848, it has some 132,000 members.

Jackson Article Appears in *Scientific American*

Martin P. A. Jackson contributed an invited article to the August issue of *Scientific American* titled "Salt Tectonics." Christopher J. Talbot, chairman of the Department of Geology and Mineralogy at the University of Uppsala, Sweden, is co-author of the article. Jackson described working with the journal as a completely new experience because he and Talbot were able to write in a less technical style, interact with journalist-editors, and use color to illustrate the article, which describes and explains salt deformation at scales ranging from grain size to the largest known intrusive and extrusive salt structures.

Major Receives National Honor

Research Associate R. P. Major received a Citation for Excellence of Service from the U.S. Secretary of the Interior for his participation in the Pacific Enewetak Crater Exploration (PEACE) program during 1984 and 1985. Major contributed to the program while working for the U.S. Geological Survey as a National Research Council Postdoctoral Associate and while an assistant professor at the University of Colorado at Denver. The PEACE program involved geological investigations of two large craters caused by nuclear testing in the 1950's in the Marshall Islands at Enewetak Atoll. Major made onsite descriptions of cores recovered during test borings and selected samples for geochemical analysis.

Bureau Hosts Distinguished Speakers

The Bureau hosted two distinguished visitors in the spring, Dr. Norbert Clauer and Dr. Birger Dahl.

Clauer, head of the Centre de Sedimentologie et de Geochimie de la Surface at the Centre National de la Recherche Scientifique in Strasbourg, France, spent several days in Texas discussing collaborative research with colleagues at SMU and the Bureau. During his Bureau visit, Clauer held a workshop, delivered a lecture, and joined a field trip to the Llano Uplift to examine exposures of Paleozoic glauconite and related rocks.

Dahl, head of the Geochemistry Division of Norsk Hydro, Norway, presented a lecture at the Bureau titled "Application of a Fully Integrated Quantitative Basin Analysis Model: Oseberg Area, Norwegian North Sea."

Research Staff Publications and Activities

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

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Lectures and Public Addresses

Saleem Akhter

"Hydrologic Characterization of Texas Gulf Coast Saline Sediments Used for Deep-Well Injection of Hazardous Chemical Wastes": presented to Environmental Protection Agency, Class I Hazardous Waste technical workshop, Denver, Colorado.

Virgil E. Barnes

"History of Geologic Research in Llano Region": presented to Austin Geological Society, Central Texas field trip.

"Tektites": presented to Austin Paleontology Club, Austin, Texas.

Robert W. Baumgardner, Jr.

"Correlation between Stress, Fracture Orientations, and Lineaments, East Texas and Northwest Louisiana": presented to Gas Research Institute, Tight Gas Sandstone Project staff, fracture workshop, Austin, Texas.

"Lineament Analysis, a Supplement to Subsurface Fracture Studies: Landsat and Radar Study of East Texas": presented to Texas Natural Resources Information System, Geographic Information Systems and Remote Sensing Symposium, Austin, Texas.

Don Bebout

"Characterization of the Grayburg Reservoir in the Dune Field, Crane County, Texas": presented to American Association of Petroleum Geologists, Student Chapter, Texas Tech University, Lubbock, Texas.

"Characterization of San Andres/Grayburg Reservoirs, West Texas": presented to The University of Texas at Austin, Department of Geological Sciences, soft rock seminar.

"Geological Setting of the Dune Field": presented to The University of Texas System, conference with University Lands operators, Midland, Texas.

Bernard Célérier

"Extensional Models for the Evolution of the Eastern U.S. Continental Margin: Example of the Carolina Trough": presented to The University of Texas at Austin, Department of Geological Sciences, technical session; The University of Texas at Dallas, Geosciences Department, seminar.

Jules R. DuBar

"Paleontological Potpourri": presented to Austin Geological Society, Austin, Texas.

Alan R. Dutton

"Application of Hydrogeochemistry and Stable Isotopes in Interpreting Ground-Water Flow Patterns—Examples from the Permian Basin": presented to Ohio State University, Department of Geology, Columbus, Ohio.

"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, hydrogeology field course class.

"Interpretation of Regional Hydrogeologic Setting of the Palo Duro Basin Using Hydraulics and Aqueous Geochemistry": presented to Midland College, introductory hydrology class, Midland, Texas.

Shirley P. Dutton

"Diagenetic History of Pennsylvanian Fan-Delta Arkosic Sandstones, Anadarko Basin: Geochemistry, Paleohydrology, and Reservoir Quality": presented as part of the American Association of Petroleum Geologists 1986–1987 Distinguished Lecture Program to the following groups: Austin Geological Society, Austin, Texas; The University of Texas at El Paso; Panhandle Geological Society, Amarillo, Texas; University of Oklahoma, Norman, Oklahoma; University of Missouri at Rolla; Washington University, St. Louis, Missouri; University of Kentucky, Lexington, Kentucky; Vanderbilt University, Nashville, Tennessee; University of Alabama, Tuscaloosa, Alabama; Louisiana State University, Baton Rouge, Louisiana; Texas A&M University, College Station, Texas; University of Cincinnati, Cincinnati, Ohio; University of Akron, Akron, Ohio; Pittsburgh Geological Society, Pittsburgh, Pennsylvania; Ohio State University, Columbus, Ohio; University of Rochester, Rochester, New York; Notre Dame University, South Bend, Indiana; Ball State University, Muncie, Indiana; University of Illinois, Champaign, Illinois; Illinois Geological Society, Olney, Illinois; Southern Illinois University, Carbondale, Illinois.

"Petrography and Diagenesis of the Lower Cretaceous Travis Peak (Hosston) Formation, East Texas": presented to Shreveport Geological Society, Shreveport, Louisiana; East Texas Geological Society, Tyler, Texas; Friends of the Mesozoic, Houston, Texas.

Robert J. Finley

"Contrasts in Gas and Oil Supplies: Is There a Coming Gas Shortage?": presented to Austin Geological Society, Austin, Texas.

"Exploration, Development, and Geological Futures": presented to Dallas Geological Society, Dallas, Texas.

"Future Texas Gas Supplies": presented to Texas Independent Producers and Royalty Owners Association, annual convention, Corpus Christi, Texas.

"Gas Reserve Growth Potential": presented to Energy Modeling Forum 9, Banff, Alberta, Canada.

"Geological Reservoir Characterization for Reserve Growth and Field Development": presented to American Association of Petroleum Geologists, Southwest Section, keynote address, annual meeting, Dallas, Texas.

"Integration of Advanced Geological Reservoir Models and Hydrocarbon Reserve Growth Analysis": presented to The University of Texas at Austin, Department of Petroleum Engineering.

R. Stephen Fisher

"Origin and Evolution of Deep-Basin Brines, Palo Duro Basin, Texas Panhandle": presented to Geological Society of America, Penrose Conference on Geochemistry of Sedimentary Basin Brines, Oxnard, California.

W. L. Fisher

"An Adequate Energy Resource Base": presented to Jefferson Energy Foundation, Town Hall meeting, Pittsburgh, Pennsylvania.

"Averting Future Energy Crises": presented to Outer Continental Shelf Policy Advisory Board, San Francisco, California.

"Capability of the U.S. Oil and Natural Gas Resource Base": presented to City College of New York, Energy Forum, New York.

"Eighteen Months after the Crash": presented to Independent Petroleum Association of America, Dallas, Texas.

"Fossil Fuel Availability": presented to National Governors Association, Washington, D.C.

"The Future of Exploration—Getting Efficient with Small Fields": presented to American Association of Petroleum Geologists, Southwest Section, keynote address, annual meeting, Dallas, Texas.

"Marginal Oil and Gas Resources and Geological Futures" and "The Price of Oil": presented to Bowling Green State University, Mayfield Distinguished Lecture series, Bowling Green, Ohio.

"Marginal Resources and Industrial Capacity": presented to University of Delaware, Newark, Delaware.

"Natural Gas as a Long-Term Stable Resource": presented to Fourth Annual Natural Gas Symposium, Oil Daily and Natural Gas Weekly, keynote address, Houston, Texas.

"The Necessity of Oil Price Stabilization": presented to Petroleum Industry Research Foundation, National Press Club, Washington, D.C.

"New Frontiers in Old Areas: Rediscovering the Resource Base": presented to American Association of Petroleum Geologists, Mid-Continent Section, annual meeting, Tulsa, Oklahoma.

"Oil and Gas Research Directions": presented to DOE/Basic Energy Sciences Workshop on Not Yet Visible or Recoverable Hydrocarbons, banquet address, The Woodlands, Texas.

"Oil and Gas Supply Outlook, Perspective from the Resource Base": presented to Independent Petroleum Association of America, Supply and Demand Committee, Austin, Texas.

"Oil Prices: Who Is Calling the Shots?": presented to Desk and Derrick Club, San Antonio, Texas.

"Perspective of the Gulf States": presented to Outer Continental Shelf Advisory Board, Corpus Christi, Texas.

"The Price of Oil": presented to Town and Gown, Austin, Texas.

"Reserve Growth and the Emergence of Moderate-Cost Oil": presented to The University of Texas System, conference with University Lands operators, Midland, Texas.

"The U.S. Oil and Natural Gas Resource Base: Capacity for Stable Production": presented to International Association of Energy Economists, Washington, D.C.

"What We Have Learned or Should Have": presented to Gulf Coast Association of Geological Societies, annual meeting, keynote address, San Antonio, Texas.

Graham E. Fogg

"Geologic Variability in Clastic versus Carbonate Depositional Systems: Perspectives on Geologic Description of Aquifers and Reservoirs": presented to Stanford University, Department of Applied Earth Sciences, Stanford, California.

"Geostatistical Analysis of Aquifer Connectivity and Equivalent Permeability": presented to Stanford University, Department of Applied Earth Sciences, Stanford, California.

"Geostatistical Analysis of Porous Media Interconnectedness": presented to Society of Petroleum Engineers, Forum on Improved Reservoir Descriptions, Durango, Colorado.

"Geostatistical Analysis of Reservoir Interconnectedness": presented to University of Houston, Department of Chemical Engineering, Houston, Texas.

"Incorporating Geology in Geostatistics": presented to North American Council on Geostatistics, annual meeting, Tucson, Arizona.

"Reservoir Modeling and Simulation, Dune Field": presented to The University of Texas System, conference with University Lands operators, Midland, Texas.

Edgar H. Guevara

"Reexploration Potential of the Benedum (Spraberry) Field": presented to The University of Texas System, conference with University Lands operators, Midland, Texas.

Thomas C. Gustavson

"Controls on Sedimentation in Malaspina Lake": presented to Geological Society of America, Penrose Conference on Glacial Facies Models, Toronto, Canada.

"Depositional Environments of the Miocene-Pliocene Ogallala Formation, Texas Panhandle and Eastern New Mexico": presented to Ogallala and Blackwater Draw Formations Symposium, Lubbock, Texas.

"Effects of Dissolution of Permian Salt on Late Tertiary and Quaternary Landscape Evolution and Sedimentation": presented to Ogallala and Blackwater Draw Formations Symposium, Lubbock, Texas.

"The Malaspina Glacier as a Modern Analog for the Late Wisconsinan Laurentide Ice Sheet": presented to Geological Society of America, Penrose Conference on Glacial Facies Models, Toronto, Canada.

Claude R. Hocott

"High Tech Comes to the Oil Patch": presented to student delegates, Society of Petroleum Engineers, annual meeting, Dallas, Texas.

"Production Characteristics of the Dune Field": presented to The University of Texas System, conference with University Lands operators, Midland, Texas.

Susan D. Hovorka

"Two Marine Evaporite Cycles: Lower San Andres Unit 2 and Lower San Andres Unit 5C": presented to

Society of Economic Paleontologists and Mineralogists, midyear meeting, core workshop sponsored by Bureau of Economic Geology, Austin, Texas.

M. P. A. Jackson

"New Insights on Salt Diapirism from the Great Kavir, Central Iran": presented to Houston Geological Society, Houston, Texas.

"Secrets of the Great Kavir: How Diapirism Works": presented to Austin Geological Society, Austin, Texas.

David A. Johns

"Examples of Paleosols Recognized in Core from the Triassic Dockum Formation, Texas Panhandle": presented to Geological Society of America, Penrose Conference on Paleoenvironmental Interpretation of Paleosols, Warm Springs, Oregon.

Charles Kerans

"Karst History and Dolomitization of Ellenburger Reservoirs, West Texas": presented to Society of Economic Paleontologists and Mineralogists, Permian Basin Section, monthly meeting, Midland, Texas.

"Karst Processes and Products and Their Impact on Reservoir Development": presented to The University of Texas at Austin, Department of Geological Sciences, soft rock seminar.

"Reexploration Potential of the Emma (Ellenburger) Field" and "Reexploration Potential of the Taylor-Link Field": presented to The University of Texas System, conference with University Lands operators, Midland, Texas.

David W. Koppenaal

"Mass Spectrometry of Inductively Coupled Plasmas": presented to Southeast Texas Mass Spectrometry Discussion Group, Houston, Texas.

"Plasma Spectroscopic Analysis Techniques": presented to Central Texas Materials Analysis Society, Austin, Texas.

Charles W. Kreitler

"Deep-Well Injection of Chemical Waste": presented to The University of Texas at Austin, Department of Civil Engineering.

"Fluid Discharge from Sedimentary Basins": presented to Society for Geochemical Exploration, Dallas, Texas.

"Geochemistry of Brines in the East Texas Basin": presented to Geological Society of America, Penrose Conference on Geochemistry of Sedimentary Basin Brines, Oxnard, California.

"Hydrogeology of Potential Low-Level Sites in Trans-Pecos Texas": presented to U.S. Geological Survey Workshop on Low-Level Nuclear Waste Site Investigations, Big Bear Lake, California.

"Hydrologic and Geologic Studies of Trans-Pecos Texas": presented to Conference on Hydrology of the Mexican-American Border with an Emphasis on the Juarez-El Paso Region, Juarez, Mexico; Bureau of Radiation Control, Texas Health Department, Austin, Texas.

"Hydrologic Characterization of Saline Formations by Drill-Stem-Test Data": presented to Texas Water Commission Underground Injection Control Group, annual meeting for Texas injectors, Austin, Texas.

"Sources of Ground-Water Salinization in Parts of West Texas": presented to International Symposium on Subsurface Injection of Oilfield Brines, New Orleans, Louisiana.

"Status Report on Deep-Well Injection Research": presented to Environmental Protection Agency, Kerr Laboratory, annual meeting, Oklahoma City, Oklahoma.

Stephen E. Laubach

"Natural Fractures in the Travis Peak Formation": presented to Gas Research Institute, Forum on the Staged Field Experiment, Lake Conroe, Texas.

F. Jerry Lucia

"Geology of Carbonate Petroleum Reservoirs": presented to The University of Texas at Austin, Department of Geological Sciences, class in applied geology of energy resources.

"Permeability Estimation from Log Response in Carbonate Reservoirs": presented to Society of Petroleum Engineers, Forum on Improved Reservoir Description, Durango, Colorado.

"Petrophysics and Engineering Characteristics of the Dune Field": presented to The University of Texas System, conference with University Lands operators, Midland, Texas.

"University Lands Project and Carbonate Reservoir Characterization Studies": presented to The University of Texas at Austin, Department of Petroleum Engineering, seminar.

"The University's Role in Carbonate Reservoir Geology and Petroleum Reserve Growth": presented to the University of Montana, Missoula, Montana.

R. P. Major

"Bimineralic Ooids, Cathodoluminescent Marine Cements, and Incongruent Dissolution": presented to The University of Texas at Austin, Department of Geological Sciences, soft rock seminar.

"Reexploration Potential of the East Penwell Field": presented to The University of Texas System, conference with University Lands operators, Midland, Texas.

Stephen J. Martel

"Development and Mechanics of Fracturing in Strike-Slip Fault Zones in Granitic Rock": presented to The University of Texas at Austin, Department of Geological Sciences, hard rock/structure seminar.

Mary W. McBride

"The Bureau of Economic Geology as a Resource for Rockhounds": presented to Austin Gem and Mineral Society, Austin, Texas.

"Geology as a Career": presented to Westlake High School, Career Day program, Austin, Texas.

"Rocks and Minerals We Use": presented to Anderson High School, Science Club, Austin, Texas.

"Rocks Tell a Story": presented to Doss Elementary School, third grade class, Austin, Texas.

Marcus E. Milling

"Hydrocarbon Resources of Deep-Water Depositional Systems": presented to The University of Texas at Austin, Department of Geological Sciences, seismic stratigraphy class.

Robert A. Morton

"Depositional and Structural Framework of Plio-Pleistocene Series, Offshore Texas": presented to Bureau of Economic Geology, meeting of industry sponsors.

"Late Cenozoic Depositional Systems, Offshore Texas": presented to The University of Texas at Austin, Department of Geological Sciences, seismic stratigraphy class.

"Miocene Depositional Systems and Hydrocarbon Plays, Offshore Texas": presented to Total Minatome Corporation, exploration staff, Houston, Texas.

"Origin, Geological Development, and Recent History of Packery Channel": presented to Coastal Bend Sierra Club and Audubon Society, joint meeting, Corpus Christi, Texas.

"Review of Bureau's Geopressured Geothermal Research Program before 1986": presented to U.S. Department of Energy and EG&G, Austin, Texas.

H. Seay Nance

"Evaporites and Red Beds of the Artesia Group, Palo Duro Basin, Texas Panhandle": presented to Society of Economic Paleontologists and Mineralogists, midyear meeting, core workshop sponsored by Bureau of Economic Geology, Austin, Texas.

"Structural Control on Guadalupian Deposition along the Matador Arch": presented to The University of Texas at Austin, Department of Geological Sciences, technical session.

Elizabeth D. Orr

"RAXCO's Performance Management Seminar and Procedures for System Assessment": presented to The University of Texas at Austin, VAX Users Group, Austin, Texas.

Jonathan G. Price

"Activity-Composition Relations in Solid Solutions": presented to The University of Texas at Austin, Department of Geological Sciences, geology class.

"Beryllium Ores and Exotic Elements in Far Western Texas": presented to Rice University, Department of Geology, seminar, Houston, Texas.

"Tectonics, Volcanism, and Ore Deposits in Trans-Pecos Texas": presented to Stephen F. Austin State University, Department of Geology, seminar, Nacogdoches, Texas.

"Texas Mineral Potential": presented to West Austin Rotary Club, Austin, Texas.

Jeffrey N. Rubin

"Beryllium- and HREE-Enriched Rhyolite, Sierra Blanca, Texas": presented to The University of Texas at Austin, Department of Geological Sciences, structure/petrology seminar.

Stephen C. Ruppel

"Depositional and Diagenetic History of Permian Dolostones, West Texas": presented to The University of Texas at Arlington, Geology Department, seminar.

"Reexploration Potential of the Emma (San Andres) Field": presented to The University of Texas System, conference with University Lands operators, Midland, Texas.

Bridget R. Scanlon

"Physical Controls on Hydrochemical Variability in a Karst Aquifer": presented to The University of Texas at Austin, Department of Geological Sciences, hydrogeology seminar.

Rainer K. Senger

"Hydrochemical and Hydrological Aspects of the Edwards Aquifer—Austin Region": presented to The University of Texas at Austin, Department of Geological Sciences, graduate hydrogeology seminar.

"The Hydrogeology of the Palo Duro Basin according to the Texas Bureau of Economic Geology": presented to Pacific Northwest Laboratory, Richland, Washington.

Noel Tyler

"Extension of University Lands Research to the Greater Permian Basin": presented to The University of Texas System, conference with University Lands operators, Midland, Texas.

"Geological Characterization of Heterogeneous Reservoirs": presented to The University of Texas at Austin, Department of Petroleum Engineering, class in reservoir characterization.

"Oil and Gas Information in Texas": presented to U.S. Department of Energy and U.S. Geological Survey, co-sponsored meeting on State-Level Oil and Gas Information, Norman, Oklahoma.

"Reserve Growth Potential in Heterogeneous Permian Basin Reservoirs": presented to Society of Petroleum Engineers, Permian Basin Section, Reservoirs Study Group, Midland, Texas.

"Role of Reservoir Heterogeneity in Hydrocarbon Recovery": presented to DOE/Basic Energy Sciences Workshop on Not Yet Visible or Recoverable Hydrocarbons, The Woodlands, Texas.

E. G. Wermund

"Nonfuel Mineral Research at the Bureau of Economic Geology": presented to Central Region Cluster Meeting of State Geological Surveys and U.S. Geological Survey, Denver, Colorado.

"Relation of State Geological Surveys with Academic Departments": presented to Central Region Cluster Meeting of State Geological Surveys and U.S. Geological Survey, Denver, Colorado.

William A. White

"Geologic Processes and Their Relationship to Wetlands along the Texas Coast": presented to University of Texas Marine Science Institute, class in coastal plant ecology, Port Aransas, Texas.

"The Use of Aerial Photographs for Mapping Wetlands and Associated Depositional and Erosional Features": presented to Texas Natural Resources Information System, Geographic Information Systems and Remote Sensing Symposium, Austin, Texas.

"The Use of Photographs to Delineate Wetlands and Associated Geologic Processes": presented to The University of Texas at Austin, Geography Department, remote sensing class.

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 1987:

Saleem Akhter

"Hydrology of Gulf of Mexico Sedimentary Basin"

W. B. Ayers, Jr.

"Geology of the Sandow Lignite Mine, Calvert Bluff Formation, East-Central Texas"

Robert W. Baumgardner, Jr.

"Wellbore Ellipticity in East Texas: In Situ Stress or Fracture-Related Spalling?"

Edward C. Bingler

"Status of the Superconducting Super Collider Program: Texas and the Nation"

L. F. Brown, Jr.

"Upper Pennsylvanian and Lower Permian Depositional Sequences in North-Central Texas: Cyclic Sedimentation Revisited"

S. Christopher Caran

"Rapid Quaternary Pedogenesis, Rolling Plains of Texas"

Robert D. Conti

"Wolfcampian Depositional Systems: The Beginning of the End of Open-Marine Deposition in the Palo Duro Basin"

Reinold R. Cornelius

"The History of Iran's Great Kavir Salt Basin within an Intermontane Deformation Zone"

Kenneth M. Duncan

"Intoduction to Cricket Draw and MacDraw for the Macintosh"

"Introduction to Cricket Graph for the Macintosh"

"Introduction to Macintosh Use"

"Introduction to MacPaint and SuperPaint for the Macintosh"

"Macintosh to VAX Connectivity Using Versaterm"

Richard Edson

"Overview of the CPS-1 Contour Mapping Package"

R. Stephen Fisher

"Clay Alteration in Evaporite Environments"

W. L. Fisher

"Changing Concepts of the U.S. Oil and Gas Resource Base"

Graham E. Fogg

"Simulation of Waterflooding in Heterogeneous Reservoirs"

Susan D. Hovorka

"Early Diagenesis in Sulfates, Palo Duro Basin"

M. P. A. Jackson

"Secrets of the Great Kavir: How Diapirism Works"

Timothy Jackson

"Diagenesis of Wilcox Mudstone—Relation to Sandstone Cementation"

Charles Kerans

"Importance of Karst in Carbonate Reservoirs of West Texas"

"Principles of Transmitted Light Microscopy"

Elisabeth C. Kosters

"Mechanisms of Incorporating Organic Matter in the Subsurface"

Charles W. Kreitler

"Hydrology of Gulf of Mexico Sedimentary Basin"

Stephen E. Laubach
"Subsurface Fracture Analysis"
"Wellbore Ellipticity in East Texas: In Situ Stress or Fracture-Related Spalling?"

R. P. Major
"Depositional Facies and Field Development at Penwell Field, University Lands, West Texas"
"Origins of Cathodoluminescence in Carbonates: An Example from Pleistocene Bimineralic Ooids"
"Principles of Cathodoluminescence Microscopy"
"Principles of Fluorescence Microscopy"

Stephen J. Martel
"Late Quaternary Activity along the Owens Valley Fault Zone, Owens Valley, California"

Mary W. McBride
"Cement Industry of Texas"

Robert A. Morton
"Exploration Potential of Middle-Upper Miocene Sediments, Offshore Texas"

Prasanta K. Mukhopadhyay
"Hydrocarbon Generation and Depositional Environment of Tertiary Coals from Texas"
"Principles of Fluorescence Microscopy and Vitrinite Reflectance"

William F. Mullican III
"Geologic and Hydrologic Issues of Low-Level Radioactive Waste Disposal in Texas"

Ronit Nativ
"Mechanism Controlling Recharge into the Ogallala Aquifer"

Elizabeth D. Orr
"VAX Performance and Capacity Planning"

Jonathan G. Price
"Principles of Reflected Light Microscopy"

Bernd Richter
"Potential Sources of Salt-Water Pollution in Tom Green County, West Texas"

Michael P. Roberts
"Geographic Information Systems and Computer Mapping: Survey with Bureau Applications"

Stephen C. Ruppel
"Geochemistry and Diagenesis of San Andres Dolostones, Emma Field, West Texas"
"Principles of Cathodoluminescence Microscopy"

Rainer K. Senger
"Hydrogeology of the Northern Segment of the Edwards Aquifer—Austin Region"

Zvi Sofer
"The Organic Geochemistry of Some Peruvian Oils of the Maranon Basin"

Congressional, Legislative, and Special Testimony

W. L. Fisher
"Energy Research and Development Funding": given to U.S. House of Representatives: Committee on Appropriations; Committee on Science, Space, and Technology, Subcommittee on Energy Research and Development; Washington, D.C.; and U.S. Senate: Committee on Appropriations, Subcommittee on Energy and Water Development and Subcommittee on Interior and Related Agencies; Committee on Energy and Natural Resources, Subcommittee on Energy Research and Development; Washington, D.C.
"Geoscience Research for Sustaining Production of Oil and Gas in the U.S.": given to U.S. House of Representatives, Committee on Science, Space, and Technology, Subcommittee on Energy Research and Development, Washington, D.C.
"Production Impacts of Low Oil Prices": given to U.S. Senate, Committee on Finance, Subcommittee on Energy and Agricultural Taxation, Washington, D.C.
"Rigs to Reefs": given to Texas Senate, Committee on Natural Resources, Corpus Christi, Texas.
"Tax Incentives and Floor Prices in Oil Stabilization": given to U.S. Senate, Committee on Finance, Subcommittee on Energy and Agricultural Taxation, Washington, D.C.
Testimony on committee substitute, S.B. 328 relating to promoting economic development in the state: given to Texas Senate, Committee on Natural Resources, Austin, Texas.

Charles W. Kreitler
"Hydrogeology of Potential Low-Level Radioactive Waste Disposal Sites in Trans-Pecos Texas": given to representatives of the Mexican Government for the Texas Low-Level Radioactive Waste Disposal Authority, Dallas, Texas, and Mexico City.

Robert A. Morton and Jeffrey G. Paine
Cooperated with the Texas Attorney General's Office regarding recovery of Galveston Island from Hurricane Alicia (1983).

Jonathan G. Price
"The Issue of Access to State Lands": given to Texas House of Representatives, Committee on Envi-

ronmental Affairs, and Texas Senate, Committee on Natural Resources, Austin, Texas.

Stephen C. Ruppel

"Stratigraphy of the Palo Duro Basin": given to Nuclear Regulatory Commission and U.S. Department of Energy, Austin, Texas.

Committee Services, Offices, and Other Professional Responsibilities

W. B. Ayers, Jr.

Co-chairman of technical session and co-convener of core workshop, Modern and Ancient Coal-Forming Environments," Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Co-leader of field trip, "Geology of Lignite and Coal Resources in the Tertiary of the Northwest Gulf Coast Basin," USAID/USGS field trip for Pakistani coal geologists.

Co-leader of field trip, "Geology of Tertiary Coals in the Powder River Basin of Wyoming and Montana," Canadian Society of Petroleum Geologists, Coal Division, annual field trip.

Robert W. Baumgardner, Jr.

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

Don Bebout

Chairman, Technical Program Committee, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Co-leader of field trip, "Cretaceous Carbonates—Central Texas," Society of Economic Paelontologists and Mineralogists, midyear meeting, Austin, Texas.

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

Honorary Member, Gulf Coast Section, Society of Economic Paleontologists and Mineralogists.

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

Member, Core and Sample Preservation Committee, American Association of Petroleum Geologists.

Member, Publication Committee, American Association of Petroleum Geologists.

L. F. Brown, Jr.

Member, Geology Subcommittee, National Research Laboratory Commission.

S. Christopher Caran

Member, Geology Subcommittee, National Research Laboratory Commission.

Carolyn Condon

Co-organizer, First Symposium on Studies Related to Continental Margins, hosted by Bureau of Economic Geology, co-sponsored by Minerals Management Service and Continental Margins Committee of Association of American State Geologists, Austin, Texas.

Member, Finance Committee, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Member, Technical Program Committee, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Jules R. DuBar

Geological Society of America Representative to The University of Texas at Austin, Bureau of Economic Geology.

Shirley P. Dutton

Chairman, Awards and Judging Committee, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Delegate representing Austin Geological Society, House of Delegates, American Association of Petroleum Geologists, annual meeting, Los Angeles, California.

Distinguished Lecturer, American Association of Petroleum Geologists.

Judge of oral presentations, Society of Economic Paleontologists and Mineralogists, annual meeting, Los Angeles, California.

Robert J. Finley

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

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

R. Stephen Fisher

Coordinator for Research Groups and Continuing Education, Planning Committee, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

W. L. Fisher

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

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

Chairman, Energy Task Force, Austin Chamber of Commerce.

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

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

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

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

Liaison to American Association of Petroleum Geologists, Association of American State Geologists.

Member, Advisory Council, Gas Research Institute.

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

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

Member, Committee on Continental Scientific Drilling, National Research Council, National Academy of Sciences.

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

Member, Geology Advisory Group, Southern Illinois University.

Member, Geology Associates Advisory Board, University of Kansas.

Member, Governing Board, American Geological Institute.

Member, High-Level Nuclear Waste Disposal Committee, Association of American State Geologists.

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

Member, Institutional Self-Study Committee on Organization, Administration, and Institutional Advancement, The University of Texas at Austin.

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

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

Member, President's Policy Advisory Committee, The University of Texas at Austin.

Member, Research Committee, Interstate Mining Compact Commission.

Member, Research Committee, Interstate Oil Compact Commission.

Member, Town and Gown.

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

State Liaison Officer, Nuclear Regulatory Commission.

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

Graham E. Fogg

Member, Editorial Board, *Journal of Ground Water*.

Member, Ground-Water Committee, American Geophysical Union.

William E. Galloway

Editor, *Uranium*.

Member, Committee for "Gulf of Mexico" volume of the Decade of North American Geology series, Geological Society of America.

Member, Promotion and Tenure Committee, College of Natural Sciences, The University of Texas at Austin.

Chester M. Garrett, Jr.

Chairman, Delegates representing Austin Geological Society, House of Delegates, American Association of Petroleum Geologists, annual meeting, Los Angeles, California.

Judge, Best Paper Awards and A. I. Levorsen Award, Gulf Coast Association of Geological Societies, annual meeting, San Antonio, Texas.

Judge, Jules Braunstein Award for best poster session and Matson Award for best oral presentation, American Association of Petroleum Geologists, annual meeting, Los Angeles, California.

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

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

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

President, and Chairman of Executive Committee, Austin Geological Society.

Thomas C. Gustavson

Chairman, Institute of Tertiary and Quaternary Studies (TER-QUA), annual meeting, Lubbock, Texas.

Chairman, Ogallala and Blackwater Draw Symposium, Lubbock, Texas.

Co-chairman, Sedimentology Session IV, Geological Society of America, annual meeting, Phoenix, Arizona.

Co-leader and co-organizer of field trip, "Tertiary and Quaternary Stratigraphy of Parts of Eastern New Mexico and Northwestern Texas," Bureau of Economic Geology and Institute for Tertiary and Quaternary Studies.

Member, Kirk Bryan Award Committee, Quaternary Geology and Geomorphology Division, Geological Society of America.

Member, Panel on Quaternary Geology and Geomorphology, Geological Society of America.

Christopher D. Henry

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

Member, Atlas Editorial Board, Rio Grande Rift Consortium.

Susan D. Hovorka

Co-organizer of core workshop, "Late Paleozoic Evaporite Basins," Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Martin P. A. Jackson

Associate Editor, American Association of Petroleum Geologists Bulletin.

Member, Subcommittee on Structural Geology, Committee for Education, American Association of Petroleum Geologists.

Mary L. W. Jackson

Chairman, Newsletter Committee, Austin Geological Society.

Member, Technical Services Committee, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

David A. Johns

Co-chairman, Audio-Visual Aids Committee, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Charles Kerans

Chairman, Field Trip Committee, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Co-chairman and co-convener, Symposium on Regionally Extensive Late Dolomitization of Lower Paleozoic Strata, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Co-leader of field trip, "Carbonate Buildups and Associated Facies, Llano Uplift, Central Texas," Austin Geological Society; First Symposium on Studies Related to Continental Margins, hosted by Bureau of Economic Geology, co-sponsored by Minerals Management Service and Continental Margins Committee of Association of American State Geologists; Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

David W. Koppenaal

Member, Publicity Committee, Society for Applied Spectroscopy.

Member, D-05 (Coal and Coke) and D-34 (Hazardous Wastes) Committees, American Society for Testing and Materials.

Elisabeth C. Kosters

Co-chairman of technical session and co-convener of core workshop, "Modern and Ancient Coal-Forming Environments," Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Member, Nominating Committee, Gulf Coast Section, Society of Economic Paleontologists and Mineralogists.

Charles W. Kreitler

Chairman, Hydrogeology Division Selection Committee for Birdsall Distinguished Lecturer, Geological Society of America.

Facilitator, U.S. Environmental Protection Agency, Office of Ground-Water Protection, Workshop on Well-Head Protection Program, Washington, D.C.

Member, Hydrogeology Division Selection Committee for O. E. Meizer Award, Geological Society of America.

Stephen E. Laubach

Co-leader of field trip, "Mesozoic Thrust Faults, Tertiary Detachment Faults, and Associated Rocks, Fabrics, and Mineralization, Whipple-Buckskin-Harcuvar Area, Western Arizona and Southeastern California," Geological Society of America, annual meeting, Phoenix, Arizona.

F. Jerry Lucia

Chairman, Reservoir Characterization Panel at DOE/Basic Energy Sciences Workshop on Not Yet Visible or Recoverable Hydrocarbons, The Woodlands, Texas.

Co-chairman and co-convener, Symposium on Regionally Extensive Late Dolomitization of Lower Paleozoic Strata, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Leader of field trip, "Mega-Collapse Breccias and Associated Late-Stage Dolomitization of Ordovician Carbonates, Franklin Mountains, West Texas," Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Member, Publication Committee, American Association of Petroleum Geologists.

R. P. Major

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

Delegate representing Austin Geological Society, House of Delegates, American Association of Petroleum Geologists, annual meeting, Los Angeles, California.

Member, Awards and Judging Committee, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

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

Member, Technical Program Committee, Austin Geological Society.

Mary W. McBride

Chairman, Technical Services Committee, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Vice President, Austin Geological Society.

Marcus E. Milling

Associate Editor, American Association of Petroleum Geologists Bulletin.

Chairman, Manpower Advisory Committee, American Geological Institute.

Commissioner, Commission on Professionals in Science and Technology, American Association for the Advancement of Science.

Councilor, Geological Society of America.

Member, Centennial Symposium Selection Committee, Geological Society of America.

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

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

Member, Solid Earth Science Panel, Energy Research Advisory Board, U.S. Department of Energy.

Vice-chairman, Board of Directors, Offshore Technology Conference.

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

Robert A. Morton

Contributor, Gulf Coast Stratigraphic Cross-Section Working Group, American Association of Petroleum Geologists.

General Chairman, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Member, Committee for "Gulf of Mexico" volume of the Decade of North American Geology series, Geological Society of America.

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

H. Seay Nance

Judge, Session on Paleobathymetry; Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Member, Geology Subcommittee, National Research Laboratory Commission.

Jeffrey G. Paine

Member, Standing Advisory Committee, Southern Coastal Corridor Cultural Resource Planning Region.

Jonathan G. Price

Chairman, Central Texas Mining Section, Society of Mining Engineers.

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

Member, Energy and Mineral Resources Graduate Studies Committee, The University of Texas at Austin.

Member, Program Policy Committee, Society of Economic Geologists.

Jay Raney

Co-organizer of core workshop, "Late Paleozoic Evaporite Basins," Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Douglas C. Ratcliff

Chairman, Finance Committee, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Co-organizer, First Symposium on Studies Related to Continental Margins, hosted by Bureau of Economic Geology, co-sponsored by Minerals Management Service and Continental Margins Committee of Association of American State Geologists, Austin, Texas.

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

Member, Membership Committee, American Association of Petroleum Geologists.

Stephen C. Ruppel

Co-chairman, Audio-Visual Aids Committee, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Co-leader of field trip, "Carbonate Buildups and Associated Facies, Llano Uplift, Central Texas," Austin Geological Society; First Symposium on Studies Related to Continental Margins, hosted by Bureau of Economic Geology, co-sponsored by Minerals Management Service and Continental Margins Committee of Association of American State Geologists; Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

Noel Tyler

Chairman, Entertainment Committee, Society of Economic Paleontologists and Mineralogists, midyear meeting, Austin, Texas.

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

Member, Selection Committee for Papers, "Best of Society of Petroleum Engineers for American Association of Petroleum Geologists."

E. G. Wermund

Co-chairman, Gulf of Mexico Regional Technical Working Group, Minerals Management Service.

District Representative, American Institute of Professional Geologists.

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

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

Member, Field Trip Committee, Geological Society of America.

Member, Parking and Traffic Committee, The University of Texas at Austin, Balcones Research Center.

Member, Texas Mapping Advisory Committee.

Vice-chairman, Texas Natural Resources Information System.

University Teaching/ Continuing Education

Don Bebout

Co-instructor (with Clyde Moore) of "Cretaceous Carbonates": American Association of Petroleum Geologists, field seminar.

L. F. Brown, Jr.

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

Robert J. Finley and Stephen E. Laubach

Fracture Research Workshop: Gas Research Institute, Austin, Texas.

Robert J. Finley and Noel Tyler

"Characterization of Heterogeneous Reservoirs": U.S. Department of Energy, short course.

Graham E. Fogg

Co-instructor (with John M. Sharp, Jr.) of "Digital Methods in Hydrogeology" (Geology 391): The University of Texas at Austin, Department of Geological Sciences.

William E. Galloway

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

"Petroleum Geology—Basin and Trend Analysis" (Geology 330K): The University of Texas at Austin, Department of Geological Sciences.

"Terrigenous Clastic Depositional Systems" (Geology 383): The University of Texas at Austin, Department of Geological Sciences.

"Topics in Sedimentary Basin Analysis" (Geology 391): The University of Texas at Austin, Department of Geological Sciences.

Claude R. Hocott

"Introduction to Petroleum Engineering" (Petroleum Engineering 102): The University of Texas at Austin, Department of Petroleum Engineering.

"Petroleum Exploration and Production" (Petroleum Engineering 320): The University of Texas at Austin, Department of Petroleum Engineering.

Charles W. Kreitler

"Deep-Well Injection of Chemical Waste": The University of Texas at Austin, College of Engineering, short course on management of hazardous wastes.

Jonathan G. Price

"Reflected Light Microscopy for Sedimentary, Metamorphic, and Igneous Petrologists": Rice University, Department of Geology, short course, Houston, Texas.

Robert S. Tye

Co-instructor (with J. M. Coleman and H. H. Roberts) of "Modern Deltas": American Association of Petroleum Geologists, field seminar.

Support Staff

Administrative/Secretarial

The administrative/secretarial staff conducts the administrative, personnel, accounting, purchasing, payroll, travel, and secretarial work essential for day-to-day operation of the Bureau. The staff is also responsible for publication sales, both direct sales at the Balcones Research Center and sales orders submitted by phone or mail. Bettye A. Blitch, Executive Assistant, coordinates the work of the administrative/secretarial staff.

Cartography

Perhaps best known for its high-quality, full-color geologic maps, the cartographic section also produces a wide range of other maps, cross sections, text illustrations, slide copy, poster art, and display materials. Within this department, a publication design section prepares artwork and designs all publication covers, composes publication layouts, and pastes up camera-ready copy. A photographic section provides cover and text photographs for Bureau publications, slides for lectures and public addresses, and negatives and color proofs for maps. Richard L. Dillon, Chief Cartographer, directs the work of Cartography. In 1987 Bureau cartographers and draftspersons completed 1,244 black-and-white illustrations, 849 pieces of colored slide copy and poster art, 67 black-and-white maps or cross sections, and 4 full-color maps.

Computer Resources

The Bureau's computer system consists of a VAX 11/780 having 16 megabytes of memory, an asynchronous network of more than 120 terminals, and many peripherals, including 17 Macintosh, DEC, and IBM (or compatible) microcomputers, 5 pen plotters, an electrostatic plotter, 6 laser printers, a 4- by 3-ft digitizing station, and an image-processing workstation. VAX software includes the VMS operating system, third- and fourth-generation data base tools, and word processing, spreadsheet, and statistical packages. Graphics software includes two graphics programming libraries, and packages for business graphics, contour mapping, image processing, and data plotting in two and three dimensions. PC-based software includes programs for well log analysis, digitizing, and interactive graphics.

The computer resources section supports programming and data base applications on the Bureau's computer system and on the University's Cyber, IBM, VAX, and Cray computer systems. In 1987 the staff began developing two in-house local area networks and started work on connecting Bureau computers to UT's broad-band Ethernet system, which allows high-speed communications with computer systems on campus and at the Center for High Performance Computing at the Balcones Research Center. In addition, substantial effort was devoted to creating in-house data base systems for Bureau administration, publication processing, and core-related data management. The section also administers software-related Quality Assurance procedures to satisfy Federal contract requirements. The staff, directed by Manager Elizabeth D. Orr, consists of a systems analyst, two programmers, a system development specialist, and a computer programmer/services assistant.

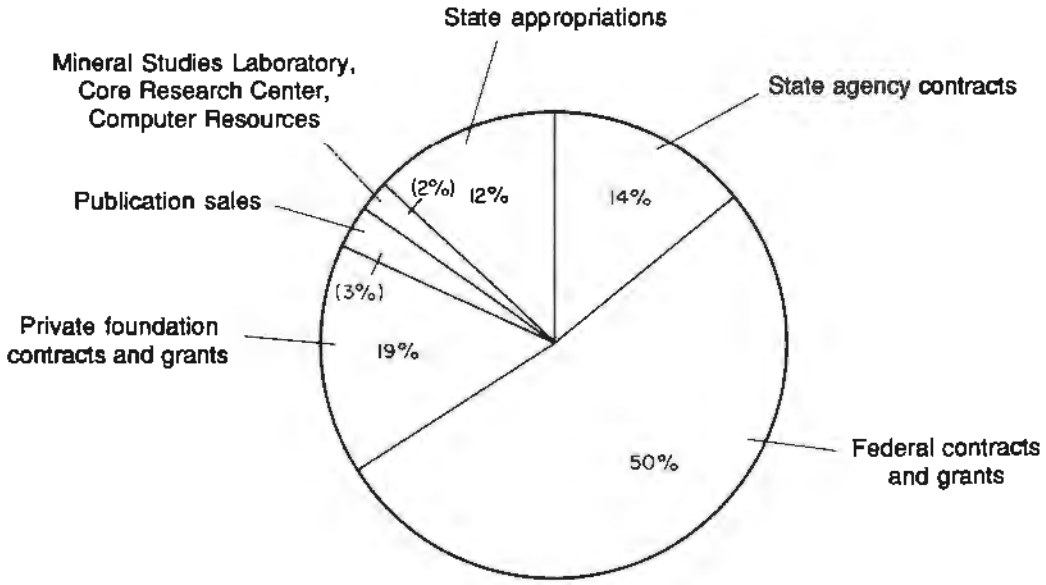
Editing

The editing section, supervised by Susann Doenges, Editor-in-Charge, consists of several editors and proofreaders who edit and proofread Bureau publications, contract reports, and papers and abstracts submitted to professional journals. A monthly in-house newsletter is also prepared by Editing. During 1987, the editing staff issued 17 new Bureau publications, 5 of which also served as final contract reports, and 24 independent contract reports. Nearly 19,000 pages of text were proofread, and more than 7,000 pages of text were edited.

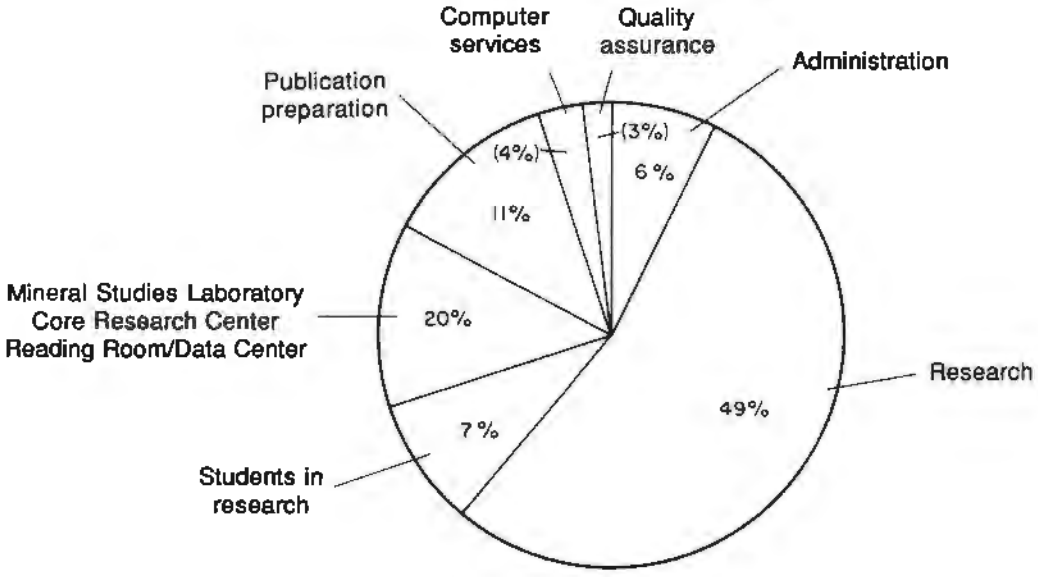
Word Processing/ Typesetting

Lucille C. Harrell supervises word processing and typesetting operators involved in processing Bureau publications and in producing camera-ready articles and contract reports. The word processing staff transfers manuscripts and first drafts keyed by researchers on the VAX computer to the dedicated word processing system. This capability allows the word processing staff to merge text from several authors into one document and to reformat documents into a consistent style before documents are submitted to contracting agencies or professional journals. Similarly, the typesetting staff transfers manuscripts from the VAX directly to the typesetter for the final steps in the publication process. The typesetting staff also produces type for word slides, posters, and figures, as well as forms for contract reports and Quality Assurance documents. During the year, almost 45,000 pages of text, tables, and forms were processed by the word processing/typesetting staff.

Sources of Funding



Uses of Funding



1986-87

BUREAU OF ECONOMIC GEOLOGY

Dr. William L. Fisher, Director
Dr. Edward C. Bingler, Deputy Director (on leave)
Dr. Robert J. Finley, Acting Deputy Director
Dr. E. G. Wermund, Associate Director for Operations, Assistant to the Director
Douglas C. Ratcliff, Associate Director for Administration
Bettye A. Blitch, Executive Assistant

Program Directors
Dr. Charles W. Kreitler
Environmental Resources
Dr. Shirley P. Dutton (Acting)
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