cite, require many changes of pore fluid. The number of pore volumes required is much greater than can be derived from compaction alone. Free convection, if it exists, is an attractive process in accounting for these observations. Three lines of evidence indicate that free convection is occurring in at least some Gulf Coast reservoirs. First, Rayleigh-Darcy calculations were made for a variety of reservoir thicknesses, permeabilities, and thermal gradients. Reasonable Gulf Coast values were selected and thermally sensitive parameters were allowed to vary with temperature. Critical Rayleigh numbers were exceeded for thick Gulf Coast sands. Depending on site-specific conditions, diagenetic reduction of permeability may create a preferred depth range for the occurrence of free convection. The second line of evidence includes pore-fluid density, silica content, and temperature data for Frio Formation waters. These data are consistent with a freely convecting system. Third, areal distribution of thermal gradients within a Frio reservoir exhibits a geometric pattern completely consistent with Bénard-type convection cells: central, upward-moving, heated plumes surrounded by polygonal zones of cooler, down-flowing waters. Therefore, free convection in Gulf Coast reservoirs is consistent with both field data (as demonstrated in the Frio Formation) and theoretical calculations.

BOARDMAN, DARWIN R., II, Texas Tech Univ., Lubbock, TX, and JOHN M. MALINKY, Smithsonian Inst., Washington, D.C.

Glacial-Eustatic Control of Virgilian Cyclothems in North-Central Texas

Virgilian strata in north-central Texas consist of repetitive sedimentary sequences called cyclothems. These cyclothems were caused by waxing and waning of glaciers in the southern hemisphere (Gondwana). During the transgressive phase, deltas were drowned, forming estuaries, and the oxygen-minimum zone responsible for the black shales in the Midland basin rose to a position well up on the shelf area, resulting in a sequence of lithofacies and corresponding biofacies which indicate a water column with stratified dissolved oxygen content. During early regression, the oxygen-minimum zone and the characteristic lithofacies and biofacies began retreating toward the Midland basin. Deltas began prograding well out onto the outer shelf, and the resulting lithofacies and biofacies depended upon the relationship between paleogeography and the prograding deltas. During maximum regression, the oxygen minimum zone was restricted to the Midland basin, and the shelf-edge carbonates were subaerially exposed, resulting in extensive freshwater diagenesis, which was responsible for enhancing secondary porosity.

BREYER, JOHN A., Texas Christian Univ., Fort Worth, TX

Coarsening-Upward Tidal Sequences in Wilcox Group in East Texas

Most exploration concepts for the Wilcox Group are based on paleogeographic reconstructions derived from maps of net sand or sand percent. Coarsening-upward tidal sequences exposed in the highwalls of two lignite mines in east Texas show the shortcomings of these reconstructions. In the past, the coarsening-upward sequences have been interpreted as prograding floodplain splays because they occur in an area of supposed fluvial sedimentation (conventional paleogeographic reconstructions show a large river system occupying the East Texas embayment during the deposition of the Wilcox Group). Recognition of the tidal origin of the coarsening-upward sequences suggests an embayed coast or a shoreline within the East Texas embayment at the time the coarsening-upward sequences were deposited—information which has exploration implications. Paleogeographic reconstructions based on maps of net sand or sand percent show time-averaged conditions. The search for the subtle trap requires paleogeographic maps based on smaller stratigraphic intervals than present reconstructions provide. These intervals can be defined by using the principles of sequence stratigraphy and tracing unconformities in the subsurface.

BURKE, HEIDI, Baylor Univ., Waco, TX

Structural Analysis of Southwest End of Dagger Flats Anticlinorium, Marathon Region, Texas

No abstract submitted.

CALAVAN, CHUCK W., Baylor Univ., Waco, TX

Depositional Environments and Basinal Setting of Cretaceous Woodbine Sandstone, Central and Northeast Texas

The Upper Cretaceous (Cenomanian) Woodbine Sandstone of central and northeast Texas has long been one of the largest oil and gas producers in Texas. North of the Angelina-Caldwell flexure, production is at moderate depths of 3,000-6,000 ft from fluvial and subaqueous deltaic facies. South of the flexure, the undifferentiated Woodbine–Eagle Ford interval produces from depths between 10,000 and 15,000 ft from fractured turbiditic channel siltstones and sandstones.

This investigation (1) more precisely defined environments of deposition, (2) determined their relationships to development of the East Texas basin, and (3) related these environments to hydrocarbon production. Much greater control was used than in previous studies, including an extensive core study (approximately 70 cores), close well control (approximately 1,200 electric logs), and an outcrop study.

In general, the depositional environments of the updip Woodbine change progressively from a complex fluvial system in the northeastern portion of the study area to delta plain, delta front, and prodelta shelf in a southwestward direction. Major fluvial axes are oriented north-northeast to south-southwest. The fluvial system includes (1) a braided stream facies, (2) a distributary channel facies, and (3) a meander belt facies. The two principal recognizable facies of the delta front are coastal barrier sands and progradational channel-mouth bar sands.

Woodbine deposition ended with transgression of Eagle Ford seas and subsequent deposition of marine shales. These shales provide a potential hydrocarbon source and seal for Woodbine reservoirs.

CARDWELL, LYNN, Cardwell Exploration Co., Midland, TX

Petroleum Source Rock Potential of Arbuckle and Ellenburger Groups, Oklahoma and North Texas

Oil and gas have been produced from the Cambro-Ordovician Arbuckle and Ellenburger Groups in Oklahoma and Texas for more than 50 years, but as yet no studies have addressed the question of petroleum source beds within these units. The solution of this problem is important in determining whether significant petroleum accumulations can be expected to be found deep within this thick and relatively unexplored section of carbonate rocks.

Detailed studies of the composition of oils produced from Arbuckle fields compared with those from Pennsylvanian fields show no discernible differences. These studies, which include determination of the composition of gasoline-range and C_{15+} saturate hydrocarbons and also saturate/aromatic/asphaltic ratios, strongly suggest that very similar source beds generated all the oils. Similar analyses of the bitumen present in nonreservoir Arbuckle and Ellenburger rocks show that very distinct differences exist between the oils and the rock bitumens. Arbuckle and Ellenburger rocks apparently were not the source beds for any of the oils investigated in this study.

Further studies of thermal maturity and organic richness of Arbuckle and Ellenburger rocks by use of pyrolysis–gas chromatographic methods reveal that this part of the section is thermally mature, and has generated at least some hydrocarbons; however, hydrocarbon and organic carbon contents are very low, indicating that commercially significant amounts of petroleum have not been generated or expelled. The lack of adequate amounts of organic matter is interpreted to be the reason that these rocks have not acted as significant petroleum sources. Based on this geochemical evidence, other, younger, rocks have generated the oils found in the Arbuckle and Ellenburger Groups.

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Upper Strawn and Canyon Cratonic Depositional Systems of Bend Arch, North-Central Texas

Terrigenous clastic and carbonate depositional systems comprising the upper half of the Strawn Group and the complete Canyon Group (Pennsylvanian) were deposited within the Forth Worth basin and on the Bend arch of north-central Texas. The stratigraphic interval involves 12 major format cycles of deltaic progradation and marine transgression. These units subdivide the outcrop and subsurface section into mappable genetic units. Variations in the rate of subsidence for the Fort Worth basin, Knox-Baylor trough, and Bend arch, as well as the initiation of subsidence to form the Midland basin, were responsible for the lithofacies geometry of individual depositional systems and gave rise to the "cyclothemic" cyclic sedimentation pattern. The effects of eustatic sea level changes have not been recognized from facies-derived evidence in north-central Texas.

Individual depositional systems have been identified and mapped using data from 4,100 well logs and 75 measured sections. For the upper Strawn (above the Brannon Bridge Limestone), subsurface isolith maps indicate the presence of four deltaic depocenters, one fan delta system, two carbonate banks, one carbonate platform, and an embayment-strand-plain complex during various stages of Desmoinesian and early Missourian deposition. Higher, within the Canyon Group, there are two deltaic depocenters, one fan delta complex, a clastic slope system, carbonate shelf-edge and shelf-interior banks, and a carbonate platform. On the basis of outcrop facies characteristics and net sandstone geometry, river-dominated and lobate deltas, as well as coarse-grained fan deltas, are the dominant clastic systems deposited on the Bend arch.

DAWSON, WILLIAM C., Houston, TX, and DONALD F. REASER, Univ. Texas, Arlington, TX

Trace Fossils in Middle and Upper Austin Chalk near Dallas, Texas—Paleoecologic and Economic Significance

In outcrops throughout northeast Texas, the Austin Group consists of interbedded thin to very thick-bedded (0.3-1.5 m) chalk with thin intervening calcareous claystone ("marl") layers. Both chalk and claystone are moderately to intensely bioturbated, and multiple generations of cross-cutting burrows are common. Austin trace fossils occur as endogenic full-relief individuals filled with chalk, clay, or iron oxides. The abundance and diversity of ichnofossils within the Austin are in distinct contrast to the paucity of other megafossils, except large, locally conspicuous inoceramids with oyster epiliths.

Variations in ichnofossil content, quality of burrow preservation, and petrographic character allow definition of three Austin substrate types. (1) Softground—vaguely mottled, argillaceous, foraminiferal biocalcilutite containing poorly preserved *Planolites, Thalassinoides*, and *Chondrites*. Burrowing is intense. *Chondrites* typically infests fillings of other ichnofossils. Inoceramids occur as widely scattered epifauna. (2) Bioclastic lenses—coarse-grained inoceramid biocalcirudite with interstitial chalk matrix. This lithology forms broad, low-relief channels; dense networks of *Thalassinoides* occur on lower surfaces. (3) Firmground—phosphatic, glauconitic, foraminiferal biocalcilutite containing well-preserved *Rhizocorallium jenense* and *Pseudobilobites*. South of Dallas, the disconformable Austin-Taylor contact is a *Rhizocorallium*-dominated firmground omission surface.

The Austin contains a shallow marine (middle to inner shelf) ichnoassemblage. A vertical increase in the ratio of suspension to deposit-feeding burrows suggests that the Austin is a shallowing-upward sequence.

Trace fossils impart textural heterogeneities to chalk which can either enhance or degrade reservoir quality and can also complicate wireline log interpretations and well completion procedures.

DE KEYSER, THOMAS, Marathon Oil Co., Houston, TX, W. F. MULLICAN, III, Texas Bur. Econ. Geology, Austin, TX, and J. E. BARRICK and C. J. GROSSNICKLAUS, Texas Tech Univ., Lubbock, TX

Ecofacies Transect of Lake Valley Shelf, San Andres Mountains, New Mexico, and Its Relation to Early Mississippian Orogrande Basin

South-central New Mexico has been well known for its excellent exposures of Mississippian strata. The Sacramento Mountains have become famous for their fortuitous exposures of the Lake Valley shelf margin. A transect of measured sections there exposes the transition from shallow carbonate shelf with beautifully developed reefs to a starved basin with isolated pinnacle reefs to the south. A new transect, to the west in the San Andres Mountains, reveals a complete shelf-to-basin transect, from shoreline to shelf-margin to starved basin. There, however, no reefs are present in time-equivalent strata. Studies there, integrating physical stratigraphy, depositional systems, microfacies analysis, and conodont biostratigraphy and biofacies, allow formulation of a leeward shelf ecofacies depositional model for the Lake Valley formation. This is combined with the Sacramento Mountains transect to delineate a model of an Early Mississippian Orogrande basin in the same position as the Pennsylvanian-Permian Orogrande basin and the present Tularosa basin. A series of such basins may have existed along the southern flank of the ancient Transcontinental arch in the southwestern United States.

DIXON, SELENA A., Geological Consultant, and DOUGLAS W. KIRKLAND, Mobil Research and Development Corp., Dallas, TX

Method of Predicting Reservoir Quality for Feldspathic Sandstones of Southern California

The diagenetic alteration of a sandstone results from the combined effects of many factors. In order to ascertain the role played by a particular diagenetic factor, the remaining diagenetic factors must be held constant. For the sandstones of the basins of southern California, we have found that the effects of almost all of the principal diagenetic factors are essentially uniform, the notable exception being thermal history. Because of this, we have been able to evaluate the diagenetic imprint of temperature upon the sandstones. Measured reservoir property data taken on core samples of reservoir sandstones from 16 fields in the Los Angeles, Ventura, and San Joaquin basins were used to determine the average rate of porosity and permeability loss with depth for each field. A straight line appears to be the proper representation for the porosity vs. depth profiles for the interval of interest. The slope of this line is defined here as the porosity gradient. Porosity gradients for the fields investigated range from 1.1% to 5.8%/1,000 ft. A direct relationship exists between the porosity gradient and the present geothermal gradient for the 16 fields which have been examined. As geothermal gradient increases, porosity gradient increases. The correlation coefficient between these variables is +0.916 for geothermal gradients between 1.6°F and 2.2°F/100 ft. A similar relationship also exists between the rate of permeability loss with depth and the geothermal gradient, but the average deviation from the mean permeability value is so great the relationship has little practical significance.

EHLMANN, ARTHUR J., Texas Christian Univ., Fort Worth, TX, and RITA J. EHLMANN (deceased), Murjo Oil & Royalty Co., Fort Worth, TX

Aledo Southeast 1,200-Ft Strawn Gas Field and Associated Deeper Production, Southeast Parker and Southwest Tarrant Counties, Texas

Most of the gas production in this region comes from earlier shallow zones (< 2,000 ft) in the lower Strawn or from deep zones (4,000-6,000 ft) in the Atoka to Marble Falls. The reservoirs, except for minor production from carbonates, are in clastic strata ranging from conglomerate to fine sandstone that are sporadic, lensing bodies of limited areal extent. The production is from clastics that occur in an eastward-thickening sequence lying just west of the Ouachita foldbelt.

The Aledo Southeast 1,200-ft Strawn field is one of the most profitable gas fields in the area. The marked linearity of this field demonstrates that the productive sand body is of fluvial origin. Its general east-west orientation indicates a fluvial system that flowed westward from the Ouachita highlands, and its flared shape on the western end suggests shoreline redistribution of the sands. Study of core and cuttings clearly reveals fluvial features, such as mud clasts, ripple laminations, wood fragments, and slump structures.

Detailed mineralogic analyses by x-ray diffraction and scanning electron microscopy indicate the shallow and deep reservoirs are feldspathic sandstones that are variously limy or dolomitic and contain major amounts of kaolinite and lesser amounts of illite, chlorite, and mixed layer clays.

Isopach maps combined with structure contour maps show the field is a trap formed where an east-west channel sand is tilted downward on the north side intercepting a gas-water contact. The south (updip) margin is a sand pinch-out. A marked sag, caused by differential subsidence, intercepts the gas-water contact and interrupts continuous production along the channel beneath the Parker-Tarrant county line.

GARRETT, CHRISTOPHER H., and RICHARD H. SNYDER, Core Laboratories, Inc., Dallas, TX

Use of Core-Measured Fracture Patterns in Exploration and Exploitation Strategy

Optimum results are obtained from core fracture studies when the core can be oriented. There are two approaches to core orientation: downhole orientation and surface orientation. Downhole core orientation is most