solubility at higher hydrostatic pressures owing to the weight of the overlying water column; the gas subsequently exsolved because of uplift and erosion during the Tertiary.

RIGGS, STANLEY, R., SCOTT W. SNYDER, and RICHARD K. SPRUILL, East Carolina Univ., Greenville, NC

Ferruginization and Phosphatization of Foraminifera in Pleistocene/Holocene Sands on Mid-Atlantic Continental Shelf

Pleistocene/Holocene sands up to several meters thick, which contain 5% to 40% phosphate grains, occur on the continental shelf of Onslow Bay, North Carolina. Altered foraminiferal specimens, 98% of which belong to the genus *Quinqueloculina,* exhibit gradational surface discoloration (white to dark yellow-brown) that progresses from late to early-formed chambers. The percentage of extensively altered specimens varies directly with phosphate concentration in the sand fraction. Microprobe analyses of polished sections from completely discolored specimens indicate that alteration involves a decrease in %CaO and concomitant enrichment in %FeO and %P_2O_5. Degree of alteration diminishes from the outside to the inside of exterior-facing chamber walls (mean values are: 70 to 78 to 82% CaO; 18 to 11 to 7% FeO; 0.8 to 0.5 to 0.4% P_2O_5). Interior chamber walls are less altered (mean values are: 84% CaO, 6% FeO, 0.3% P_2O_5). On a CaO-FeO-P_2O_5 diagram the compositional changes through successive chambers of a single specimen parallel those from unaltered through altered specimens. The chemical compositions of completely discolored specimens fall on a proposed alteration trend between unaltered calcareous specimens and chamber fillings. Chamber fillings contain 0.9% CaO, 49% FeO, 12% MgO, and 1.6% P_2O_5; they are generally black. Relative concentrations of CaO-FeO-MgO plot within the compositional range of siderite and magnesite. Constant MgO values (7.5%) in altered foraminiferal tests demonstrate that initial diagenesis involves conversion to high-magnesium calcite. Subsequent alteration is largely ferruginization and minor phophatization of the test and the diagenetic materials forming within the chambers.

RIGHTMIRE, C. T., TRW Inc., McLean, VA

Coal Beds—Source Rock and Reservoir

Coal beds are known to exist in parts of almost all major sedimentary basins in the conterminous United States from outcrop to depths in excess of 15,000 ft (4,570 m). Coal-bearing strata often exist interbedded with tight gas reservoirs, making it very difficult to differentiate the tight gas resource from the methane-from-coal beds resource. Studies of the methane-from-coal beds resource have determined that it may exceed 400 tcf. Measurements of methane in coal beds have shown that much gas generated during coalification is not currently present in the coal beds and may have escaped into stratigraphically contiguous formation which are now tight gas reservoirs.

Bituminous coals have been analyzed that contain more than 600 ft^3 of methane per ton of coal, or approximately 1 mmcf of gas per acre-foot of coal. More than 5,000 ft^3 is generated during the thermochemical alteration of peat to the low volatile bituminous-semi-anthracite boundary. Only a fifth to a third of that gas appears to be retained in the coal. The excess gas may be a source for other reservoirs.

Analysis of coal samples collected throughout the United States shows gas contents ranging from less than 25 ft^3/ton for subbituminous coals in the Powder River and San Juan basins to more than 500 ft^3/ton for coals in parts of the Green River, Raton, San Juan, and Appalachian basins. In the Powder River basin, where the coal resource is very large, even the low gas content coals have potential as producing gas reservoirs.

RIGSBY, CATHERINE A., Louisiana State Univ., Baton Rouge, LA

Provenance and Depositional Environments of Middle Eocene Canoe Formation, Big Bend National Park, Brewster County, Texas

The middle Eocene Canoe Formation contains the first sedimentologic evidence of local volcanism in the Big Bend region. Sediments comprising the formation's lower member, the Big Yellow Sandstone, were deposited by sandy braided streams which were scoured by ancient carbonate highlands and volcanic terranes to the west. The unit represents a continuation of the depositional styles and compositional trends recorded in the Paleocene and early Eocene strata of the region. In contrast, sediments comprising the upper, unnamed member of the Canoe Formation were deposited as a volcanic sediment apron on the fringes of the newly forming Chisos Mountains volcanic center. The sandstones (feldspathic litharenites and lithic arkoses) are dominated by volcanic rock fragments and, as such, document an abrupt change in depositional style and sediment composition brought about by the onset of local volcanism.

A comparison of Canoe Formation and earlier Tertiary sediment compositions results in the delineation of distinct petrologic trends which record the tectonic evolution of the early Tertiary sediment source area. The Paleocene sediments of the area were derived primarily from ancient magmatic arcs in northeastern Mexico. With the onset of the Laramide orogeny in late Paleocene-early Eocene, a new source of sediment—newly uplifted carbonate highlands—was added. Local volcanism in the middle Eocene produced yet another source of sediment, lava flows, ash flow tuffs, and sand-size pyroclastic materials from the Chisos Mountain volcanic center. Rapid erosion of these materials produced volcanic sediment aprons such as the one described here. As regional volcanic activity increased, typical Paleocene and early Eocene depositional styles may have been completely abandoned, especially in areas proximal to the volcanic centers.

ROADIFER, ROY, Mobil Oil Corp., New York, NY

Size Distributions of World's Largest Known Oil and Tar Accumulations

Gross volumes of oil, which must be kept in mind by resource estimators to address the volume/size framework, may be thought of in order from largest to probably smallest volumes as follows: (1) generated; (2) dissipated; (3) degraded, partially preserved; and (4) trapped and conventionally producible. Basic knowledge of these volumes may be from greatest to least in essentially reverse order.

The 332 largest known accumulations (less than 1% of the total number) account for more than three quarters of the known 8.2 trillion bbl of oil and heavy oil or tar in more than 35,000 accumulations in the world. About 2.6 trillion bbl of estimated undiscovered conventional oil added to the known volume of 8.2 trillion bbl yields a total of 10.8 trillion bbl known or reasonably estimated. Worldwide cumulative production of about 461 billion bbl of oil accounts for only 4% of the gross.

Oil in place must be estimated for conventional oil fields before comparison with heavy oil and tar accumulations. The size range of accumulations considered in the size distribution of the 332 largest known accumulations is from 0.8 to 1,850 billion bbl of oil. The smallest conventional fields in the distribution are about 1 billion bbl because the size cutoff is 0.5 billion bbl of oil recoverable. The size distribution of the 332 largest known accumulations approaches log normal and is overwhelmed by the largest 3 supergiant tar deposits which hold nearly half of the total 6,267 billion bbl.

Globally, the largest 3 accumulations, all heavy oil or tar, are in South and North America; the 2 largest conventional oil fields are in the Middle East. Prudhoe Bay and east Texas fields rank 25th and 35th respectively in descending size order.

ROBERTS, HARRY H., Louisiana State Univ., Baton Rouge, LA

Sedimentology of Mudflow Deposits in Mississippi River Delta-Front Environment

Shelf deposits of the active Balize Lobe of the Mississippi River delta, are constantly displaced from their original depositional environments by a variety of deformational and mass-movement processes. Consequently, hydraulically controlled sedimentation patterns are altered in favor of sediment displacement to deeper water settings. High-resolution seismic and side-scan sonar surveys have shown that complex mudflow systems are the most important means of sediment transport from the upper and intermediate delta front to deeper shelf and upper-slope environments. With expanding exploration and production of hydrocarbons from shelf depths and deeper, it has become important to identify and understand both the surficial and subsurface characteristics of sediments associated with sea floor instabilities.

The sedimentology of mudflow deposits has been determined from detailed x-ray radiography (for sediment structure) and x-ray diffraction (for clay mineralogy) analyses evaluated in conjunction with their geotechnical properties (shear strength, Atterberg limits, etc). Sediments from each major part of the mudflow system (gully heads, chutes, and mudflow lobes) share a set of common sedimentary structures. The most complicated deposits are the wide-spread and rapidly deposited mudflow lobes. They are composed of overlapping wedges of highly remolded, low-shear-strength deposits, separated by thin, interlobe units of acoustically reflective and slowly accumulated hemipelagic sediment. Gas-related features, convolute structures, inclined bedding, evidence of flowage, and indications of thorough mixing are found in mudflow lobe deposits. Clay mineral assemblages are typical of rapidly deposited prodelta clays (smectite:kaolinite:illite $\approx$4:4:1). In contrast, thin interlobe units and distal shelf sediments contain evidence of biogenic activity (micro-organism tests, burrows, and shell fragments) and diagenetic products. Interlobe and distal shelf deposits have clay mineral suites characterized by an increase in kaolinite and illite at the expense of smectite, which allows for distinction of individual flows and the general mudflow base.

ROBBIN, DANIEL M., U.S. Geol. Survey, Miami Beach, FL

A New Holocene Sea Level Curve for Upper Florida Keys and Florida Reef Tract

A new Holocene sea level curve for the upper Florida Keys and Florida reef tract has been constructed by integrating existing and new data from ^{14}C age analyses. New data are derived from 21 mangrove peat samples from 5 locations and 3 laminated $CaCO_3$ soilstone crust (caliche) samples from 3 locations. The new sea level curve is based on ^{14}C ages ranging from 360 ± 60 y.B.P. to 14,000 ± 160 y.B.P., and indicates a fluctuating sea level rise of approximately 0.3 mm/yr (from 14,000 to 7,000 y.B.P., sea level rose from 9.2 to 7.0 m, 30.2 to 23 ft, below MSL), approximately 1.2 mm/yr (from 7,000 to 2,000 y.B.P., sea level rose from 7.0 to 0.75 m, 23 to 2.5 ft, below MSL), and approximately 0.3 mm/yr (from 2,000 y.B.P. to present, sea level rose from 0.75 m, 2.5 ft, below MSL to present MSL).

No evidence was found in this area that, during the last 14,000 yr, any highstand was greater than the present sea level. The rate of rising sea level, however, has varied. Sea level stand in this area at 14,000 y.B.P. is much shallower than indicated on other published curves for the east coast of the United States.

ROBERTSON, JAMES D., ARCO Oil & Gas Co., Dallas, TX, and WILLIAM C. PRITCHETT, ARCO Exploration Co., Dallas, TX

Bright Spot Validation Using Comparative *P*-Wave and *S*-Wave Seismic Sections

Coincident *P*-wave and *S*-wave CDP lines were shot across the Willow Slough and Putah Sink fields, Yolo County, California, by the 1977-78 Conoco *P*-Wave/Shear-Wave Group Shoot. The fields produce gas from pay sands in the Cretaceous Starkey and Winters formations. Several of the thicker pay sands correlate with amplitude anomalies on the *P*-wave sections, and these amplitude anomalies are true seismic "bright spots." The equivalent events on the *S*-wave sections are much lower in relative amplitude when the overall gains of the *P* and *S* sections are balanced. The difference in the *P* and *S* responses is consistent with laboratory experiments which show that introducing gas into the pore space of a liquid-saturated rock dramatically lowers *P* velocity but minimally affects *S* velocity. The experimental lines demonstrate that comparison between the amplitudes of *P* and *S* is a diagnostic technique that can be sued to distinguish gas-liquid contacts from lithologic interfaces. An *S*-wave section validates a *P*-wave bright spot attributed to gas saturation when there is no anomalous amplitude at the equivalent *S*-wave event.

RODGERS, DONALD A., Applied Tectonics, Inc., Houston, TX

Exploration Consequences of Divergent Strike-Slip Motion on Mexia Fault Zone of Central Texas

The several proposed models for the evolution of the Gulf of Mexico suggest different types of movement on the Mexia fault zone. One recent model suggests that the Yucatan Peninsula, in the Gulf at the beginning of the Jurassic, moved southwest to its present position during the Jurassic. This requires major right-lateral strike-slip movement with minor divergence in the vicinity of the Mexia fault zone. This fault zone trends north-south, consists of en echelon horsts and grabens striking about 30° east of the zone's trend, and was active from the Jurassic through the Eocene. The presence of the grabens, their orientation and en echelon arrangement, and the age of movement are all consistent with divergent strike-slip movement.

Hydrocarbons are generally produced from the basin side of the fault zone but have also been produced from fault traps within the grabens. Theoretical models, physical models, and field examples of strike-slip faults suggest the presence of en echelon anticlinal traps along the fault zone, and development of smaller antiformal structures where the en echelon grabens overlap. Such structures have not been described along the Mexia fault and may be important new structural plays, particularly for oil in the Smackover.

Post-Jurassic movement on the fault zone enhanced the structural relief of the grabens and probably was related to the mobilization of the Louann salts. Traps in the Cretaceous which produce most of the hydrocarbons are due to this later movement.

RODRIGUEZ, ARGENIS, Univ. Toronto, Toronto, Ontario, Canada

Cyclicity Concept in a Deltaic to Shallow-Marine Environment of Deposition Concerning an Oil-Sand Setting

The need to accurately define sand trend and quality in a deltaic to shallow-marine environment of deposition where facies changes take place over a short distance is widely recognized. In an oil-sand environment, such as the Cerro Negro area of the Orinoco Petroliferous Belt, this need is more evident because enhanced recovery projects are necessary. Facies variability and correlation problems in such a setting have led many workers to apply indiscriminately the cyclicity concept as an exploration/exploitation tool. According to this concept, a cycle begins with a transgressive sand and ends with a marsh facies represented by a coal bed. Subdivision of the rock column into cycles allow delineation of sand geometry.

Recent works have demonstrated that rooted coal beds can be formed in different coastal environments, ranging from the upper delta plain to the back-barrier lagoon facies. Therefore, it is obvious that the association of these facies will differ from one another and from the standard cycle concept.

In the Cerro Negro area, the process-controlled genetic unit concept was of great help in defining sand geometry and quality. The rock column of cored wells can be subdivided according to the presence of physical and biological parameters into 4 units, differentiated by the occurrence of rooted coal, limestone, sand, shale, *Ophiomorpha*-type burrows (*Fositextura figurativa*), bioturbation structures (*Fositextura deformativa*), and shell fragments.

ROLLINS, FRANCIS O., CHRISTINE A. POWELL, and JOHN M. DENNISON, Univ. North Carolina, Chapel Hill, NC

Flexural Modeling of Devonian Catskill Delta in Eastern United States and Formation of Taghanic Unconformity

The Devonian Catskill delta is an exogeosynclinal clastic wedge in the Appalachian basin. Subsidence caused by this load is modeled as flexure of a perfectly elastic crust. Subsidence can be measured accurately in eastern New York and Pennsylvania because of excellent well and outcrop control and the ability to recognize shoreline position.

Calculated flexural response to the load of the Erian Series sediments predicts subsidence smaller than observed values, especially in the eastern portion of the delta. It is necessary to postulate an additional tectonic component of subsidence. Additional subsidence is modeled as a cosine curve decaying exponentially with distance from a point deflection of the crust. This model, plus the flexure caused by sediment load, produces subsidence consistent with observations.

The flexural response of the crust offers an explanation for an unconformity in black shales that developed during the Taghanic age on the west side of the Appalachian basin, with at least 50 m (165 ft) of expected strata missing. This unconformity expands westward and southwestward