veloped subsequently from the altered river courses as the individual continents changed shape and new embayments and seaways were opened.

During the Jurassic and Cretaceous Periods, Gondwanaland progressively fragmented into the several larger southern continents plus the numerous smaller segments which were dispersed over almost half the globe. Each pulse of separation produced sedimentary basins.

The present oceans of the Southern Hemisphere were first opened as rift systems which received essentially nonmarine sediments deposited in a tectonically active trough. As the rifts widened during Cretaceous time, the sediments became more marine. Lithology, organic content, and petroleum potential were determined by the nature of the source material, water depth, and paleolatitude. Separation of the continents continued throughout the Cenozoic and current observations suggest that the rifting process and ocean widening are still active.

Oil reserves in excess of 25 billion bbl and gas reserves of several trillion cubic feet may be attributed to the fragmentation of Gondwanaland. Typical producing provinces include the Reconcavo, Gabon, and Gippsland Shelf basins as well as the Niger and Nile deltas. Most of the petroleum reserves have been developed during the past decade.

MCIVER, RICHARD D., Esso Production Research Co., Houston, TX 77001

Origin and Distribution of Natural Gas

Components of natural gases may come from a variety of sources, but the composition and extent of diagenesis of sedimentary organic matter probably control regional patterns of gas composition. Chemical analyses of suites of samples from different depths within single shale units indicate that the kerogen in ordinary shales may be the source of the order of 1 Tcf of methane gas and smaller amounts of carbon dioxide and nitrogen per cubic mile of shale. The process of generation is similar to coalification, as are the products.

Relative proportions of gases depend on differences in original constitution of starting materials and on the stage (*i.e.*, early or late) of maturation. The progression is from relatively more nitrogen in early stages, to more carbon dioxide, and finally to very large quantities of methane. Other sources must be called on to account for local anomalous gases, such as those very rich in H_2S and CO_2.

MEISTER, EGON M., and NESTOR AURICH, PETROBRÁS, Rio de Janeiro, Brazil

Geologic Outline and Oil Fields of Sergipe Basin, Brazil

In the Sergipe basin of northeastern Brazil a Lower Cretaceous unconformity marks a change in general depositional environment and tectonic style. Below this unconformity, Carboniferous to Lower Cretaceous beds are nonmarine, whereas the overlying Lower Cretaceous to Tertiary beds are dominantly marine. A period of intense normal faulting which preceded the unconformity resulted in an uplift which exposed Precambrian rocks in an area north of Aracaju, while in adjacent grabens thick wedges of syntectonic conglomerates were deposited locally over older sediments. Irregularities on this unconformable surface were filled by the Carmópolis Member of the Muribeca Formation, a conglomerate and coarse sandstone; the more extensive overlying Ibura Member evaporites of the same formation also covered the areas where basement was still exposed.

Late Cretaceous tectonism is characterized by small-scale faulting; the Riachuelo-Siririzinho and Vassouras-Carmópolis oil trends resulted from a combination of northwestward subsidence of basin-margin grabens and a regional southeastward tilting that started somewhat later.

Oil production in this basin from the Carmópolis, Siririzinho and Riachuelo fields comes mostly from the Carmópolis Member. Some oil is also produced from Lower Cretaceous reservoirs in contact with the unconformity. Depth range of all reservoirs is 400–800 m.

Favorable conditions for oil accumulation are the result of adequate structural evolution during Late Cretaceous time, presence of evaporites and probable oil source organic shales at the top of the reservoirs, and younger unconformities not reaching down to the trap. Locally, lateral permeability barriers or reservoir pinchouts complement the structural trap closure.

The oil is of mixed base ranging from 24 to 30.5° API. Cumulative production to December 31, 1969, with Siririzinho and Riachuelo fields still being developed, was 23.65×10^6 bbl of oil. This production comes from 205 completed wells drilled in a grid of 400 m.

MEYERHOFF, A. A., AAPG, Tulsa OK 74101

Major Discrepancies in Current Sea-Floor Spreading Models

Studies of sea-floor spreading models from the viewpoints of paleontology, climatology, meteorology, and physical oceanography reveal serious discrepancies in these models. For example: (1) Late Paleozoic-Mesozoic tetrapod distribution reveals that the generic identity between Africa and South America is only 4%. There are no tetrapod genera common to southern Africa and Australia. (2) The dicynodont reptile, *Lystrosaurus,* has been found in Antarctica, South Africa, India, and western China, but not in Australia and South America. *Lystrosaurus* appears to be aquatic. (3) Eighteen freshwater ostracod species are common to western Africa and eastern South America, but there are few common marine species. Birds and large flying insects carry freshwater ostracod larvae today between continents; no doubt they did so in the past. (4) Species-diversity gradients are symmetrical with respect to the present pole at least as far back as Permian time. (5) Faunal realm studies of certain Mississippian and Triassic marine families show that migration between North America and Europe was via several Arctic routes. North American benthonic faunal identities with Europe at the specific level appear to be higher *today* (8%) than at any time in the geologic past (average, about 5%). (6) The presence of 95% of all evaporites, middle Proterozoic through the present, in areas underlain by today's dry wind belts shows that lower atmosphere circulation patterns have remained almost unchanged for 1 billion years—a physical impossibility unless the rotational axis, continents, and ocean basins have remained stable since middle Proterozoic time. (7) Because of a lack of moisture, coal could not have formed in the interiors of Laurasia or Gondwanaland. (8) Tillite distribution leads to the same conclusions as for coals. (9) Surface and subsurface continuity of stratigraphic units and paleontologic zones from the central India shield to central Afghanistan and Iran proves that India has been a part of Asia since the latter part of Proterozoic time.

MOORE, CARL A., School Petroleum and Geol. Engineering, Univ. Oklahoma, Norman, OK 73069

Geologic Factors Which May Affect Gas Occurrence in Anadarko Basin, Oklahoma

The Anadarko basin in Oklahoma, the Texas Panhandle, and in southwestern Kansas contains many reservoirs which produce commercial quantities of gas with subordinate quantities of oil. The producing formations are Permian; Upper, Middle, and Lower Pennsylvanian; Upper and middle Mississippian; Hunton; and Ordovician. Each of these groupings can be considered a genetic stratigraphic unit in which the depositional and structural history is closely related.

Gas analysis is a powerful tool in the exploitation of a given reservoir. Some reservoirs in the Anadarko basin are blanket-type sandstones in which the analyses will be uniform over a broad area. Gas analyses showing abnormally high BTU values, subnormal formation pressures, or exceptionally high nitrogen content can be producing from a sandstone lens (either channel or offshore bars) or a limited carbonate porosity zone in which there has been no communication of fluids.

Hunton gas analyses show a higher percentage of CO_2 at depth, whereas the BTU values decrease because of the decreasing percentage of gas liquids below 14,000 ft. Pressures in the Hunton, although a little below the so-called normal bottomhole pressures, increase in a fairly uniform manner. The Morrow sandstones are productive over most of the Anadarko basin. Variations in the analyses from these sandstones appear to depend on the depth of production and on the chemical content of the gases. It is evident that many of the anomalous values of the analyses depend on the extent of the local reservoir and its geometry.

Gas analyses are a major factor in the economics of gas production. The Hunton gases along the northern shelf of the Anadarko basin yield high percentages of valuable gas liquids. Other zones yield variable amounts of gas liquids. Nitrogen values are small in all reservoirs except in the Permian where several "noninflammable" gases are reported. In contrast with the Oklahoma and Texas panhandle gas production, helium does not appear to be a factor—only traces to less than 1.0% helium are reported.

MOORE, CLYDE H., JR., and STEPHEN A. ALLEN, Dept. Geol., Louisiana State Univ., Baton Rouge, LA 70803

Preliminary Diagenetic Model of Carbonate Beach Sequences

Detailed studies of Cretaceous Edwards carbonate beaches revealed striking vertical sequences of first generation, early diagenetic fabrics which are thought to represent the diagenetic imprint of the original hydrologic regimen on the sediments during and soon after their deposition.

The classic environmental zones of the beach can be recognized in the Cretaceous prograding beach sequences and contain, from top to bottom, the following diagenetic features.

The *backshore zone* contains penecontemporaneous dolomite, dedolomite, montmorillonite-caliche paleosoil zones; all evidence points to a meteoric-vadose diagenetic environment.

The *foreshore zone* contains much moldic porosity, micrite rims on grains, beach rock cemented during deposition by metastable carbonates; all intragranular cements have a low iron content indicating an oxidizing vadose cementation environment. These features indicate the influence of both meteoric and marine hydrologic conditions.

The *lower foreshore zone* is characterized by dominant inversion textures preserving shell structure of original aragonite grains, the notably poor development of micrite rims, the presence of early metastable carbonate cementation (beach rock) and relatively high iron content of intragranular cements. These features indicate reducing phreatic, dominantly marine hydrologic conditions during diagenesis.

The *offshore zone* contains high iron intragranular cements, multiple bored, and inverted bored surfaces. The diagenetic environment was no doubt marine phreatic.

Companion studies of Holocene carbonate beach sediments, rocks, and interstitial water confirm to a remarkable degree, the diagenetic patterns found in the foreshore and upper offshore zones of the Edwards carbonate beaches, which lends strong support to the use of these patterns as a preliminary model of carbonate diagenesis in the beach environment.

MOORE, W. RICHARD, and ROBERT R. BERG, Dept. Geol., Texas A&M Univ., College Station, TX 77843

Porosity-Cement-Depth Relation for Minnelusa Sandstones, Powder River Basin, Wyoming

Upper Minnelusa reservoir sandstones of Wolfcampian (Permian) age show a linear reduction of porosity with depth. However, porosity is not a simple function of compaction, but is related also to composition and maximum depth of burial.

Wolfcampian sandstones are fine-grained orthoquartzites that have calcite (and dolomite), anhydrite, and silica cements. From grain-packing studies in thin section, 3 stages of compaction are evident. The first stage is characterized by a linear decrease of effective porosity to 26% at 6,000 ft of maximum depth of burial, during which quartz grains and calcite clasts were compacted. The second stage is characterized by decrease in effective porosity to 10% or less by change of calcite clasts to calcite cement. The third stage of compaction is characterized by a linear decrease of intergranular porosity to 26% at 16,000 ft maximum burial during which quartz grains were compacted and calcite and anhydrite cements were dissolved and replaced by secondary silica. Intergranular porosity includes both voids and cement, as distinct from total and effective porosity.

It appears that permeability is greatly reduced at less than 10% effective porosity at a maximum burial of 12,000 ft and present drilling depths of 10,000 ft. Therefore, this depth may represent economic limits for Minnelusa exploration.

MORGAN, W. JASON, Dept. Geol., Princeton Univ., Princeton, NJ 08540

Island Chains, Aseismic Ridges, and Plate Motions

Transform fault and spreading-rate data have been reexamined and a worldwide synthesis of relative plate