Production from the Melbourne in Matagorda and Calhoun Counties is trapped primarily in closures against the upthrown sides of down-to-the-coast faults. In contrast, anticlinal closures, located on the downthrown sides of down-to-the-coast faults, form the primary traps through Aransas, San Patricio, and Nueces Counties.

A case history of the South Copano Bay field illustrates basic exploration techniques that are useful in exploring for buried depositional-type structures.

8. DERRELL A. SMITH, Shell Development Company, Houston, Texas

SEALING AND NON-SEALING FAULTS

Differentiating between sealing and non-sealing faults and their effects in the subsurface is a major problem in petroleum exploration, development, and production. The fault-seal problem has been investigated from a theoretical viewpoint in order to provide a basis for a better understanding of sealing and non-sealing faults. Some general theories of hydrocarbon entrapment are reviewed and directly related to hypothetical cases of faults as barriers to hydrocarbon migration and faults as paths for hydrocarbon migration. The phenomenon of fault entrapment reduces to a relationship between (1) the capillary pressure and (2) the displacement pressure of the reservoir rock and the boundary rock material along the fault. Capillary pressure is the differential pressure between the hydrocarbons and the water at any level in the reservoir; displacement pressure is the pressure required to force hydrocarbons into the largest interconnected pores of a preferentially water-wet rock. Thus the sealing or non-sealing aspect of a fault can be characterized by pressure differentials and by rock-capillary properties.

Theoretical studies show that the fault seal in preferentially water-wet rock is related to the displacement pressure of the media in contact at the fault. Media of similar displacement pressure will result in a non-sealing fault to hydrocarbon migration. Media of different displacement pressure will result in a sealing fault, provided the capillary pressure in the reservoir rock is less than the opposing boundary displacement pressure. The trapping capacity of a boundary, in terms of the thickness of hydrocarbon column, is related to the magnitude of the difference in displacement pressures of the reservoir and boundary rock. If the thickness of the hydrocarbon column exceeds the boundary trapping capacity, the excess hydrocarbons will be displaced into the boundary material. Dependent on the conditions, lateral migration across faults or vertical migration along faults will occur when the boundary trapping capacity is exceeded. Application of the theoretical concepts to subsurface studies should prove useful in understanding and in evaluating subsurface fault seals.

9. J. A. GILREATH, Schlumberger Well Surveying Corporation, New Orleans, Louisiana

LOG CHARACTERISTICS OF DIAPIRIC SHALES

High-pressure diapiric shales, commonly associated with domal structures along the Texas and Louisiana Gulf Coast, characteristically exhibit low values of resistivity, density, and acoustic velocity. Thus, well logs enable identification of these intrusive shale masses.

However, deep-water marine shales—of the types which are source beds for diapiric shales—also are high-pressure formations. These shales, in normal stratigraphic positions, exhibit log characteristics which are similar to those of diapiric shales. Therefore, although resistivity, density, and acoustic-velocity logs may indicate that a domal shale core may have been penetrated, additional data are required for confirmation.

Dipmeter surveys provide information to confirm or deny the intrusive nature of the shale. In addition, if the shale is found to be intrusive, dip information locates the well position with respect to the apex of the diapir. As the shale diapir is approached from above, dips (away from the apex) increase in magnitude—just as if a salt dome were being approached. Within the low-resistivity shale, the dips are relatively constant in both magnitude and azimuth, and dips approximate the dip of the contact between the bedded formations and the diapiric shale. This consistent dip within the domal core is distinctly different from the random dips found in gouge shale adjacent to piercement salt domes.

In an offshore field, resistivity values were used to map the top of a shale dome. None of the wells drilled on this structure penetrated salt. The deepest penetration into the domal shale was approximately 2,000 ft. Contour lines were drawn, using as a datum the depths where the various wells encountered a decrease in shale resistivity to 0.5 ohm-meter. The map indicates a minimum structural closure of 6,000 ft. Dips computed from the map agree closely with those measured within the domal shale by dipmeter surveys.

10. ROBERT S. DOLLISON, Pan American Petroleum Corporation, Houston, Texas

BIG HILL FIELD, JEFFERSON COUNTY, TEXAS

Big Hill field is in the Frio sand trend on the western flank of the Big Hill salt dome. Multiple reservoirs in Miocene and Oligocene sandstones are on the downthrown side of a regional, up-to-the-coast growth fault across which early Miocene and older sediments increase in thickness by 57%. One reservoir in the Oligocene Hackberry is bounded by two growth faults and an unconformity (Hackberry unconformity). The hydrocarbons trapped in this reservoir evidently were generated within the surrounding rocks. An isopachous map of the interval between the top of the Frio and the Hackberry unconformity indicates that growth of the Big Hill salt dome occurred prior to the close of Frio time, and that the crest of the dome was north of the present-day salt spine. This map also suggests the presence of a buried, down-to-the-coast growth fault which traverses the western flank of Big Hill field but which does not intersect any wells.

Pressure-performance histories of two reservoirs and of two wells producing from other reservoirs are shown graphically in order to illustrate the problems involved in explaining wells that are in pressure communication. Four gas-fluid contacts in a continuous *Marginulina* sandstone reservoir differ in elevation by 600± ft. These original gas-fluid contacts were established by the migration of hydrocarbons into a complexly faulted area. Accumulation of oil downdip from these gas-fluid contacts can be explained reasonably in terms of gravity-segregation effects.

11. JAMES P. SPILLERS, Louisiana State Mineral Board, Baton Rouge, Louisiana

DISTRIBUTION OF HYDROCARBONS IN SOUTH LOUISIANA BY TYPES OF TRAPS AND TRENDS—FRIO AND YOUNGER SEDIMENTS

INTRODUCTION

Since Frio time, the south Louisiana part of the Gulf Coast geosyncline has been characterized by regressive sedimentation, progressive southward and eastward shifting of successively younger depocenters, southward thickening of all sedimentary units (penetrated by the drill), a general progressive increase in the rate of sedimentation, and a gradual retreat of the Gulf of Mexico. The depositional units normally exhibit three gross facies: (1) continental facies, composed predominantly of massive sandstone with minor intercalations of clay deposited in deltaic floodplain, littoral, and marsh environments; (2) transitional facies, composed of deltaic complexes (mostly sandstone) and marine sandstone interbedded with marine shale deposited in deltaic and inner neritic environments; (3) marine facies, composed predominantly of deep-water marine shale and lesser marine sandstone deposited in the neritic and the innermost bathyal environments. Most of the oil, condensate, and gas production in south Louisiana is derived from sandstone reservoirs in the transitional facies. The transitional facies, which is arranged in approximately east-west trending belts, is the locus of the producing trend. From the gross viewpoint, the stratigraphy and structure of the area are relatively simple, consisting of a layered sequence of terrigenous clastic sediments which has gradually extended outward into the Gulf of Mexico and which is underlain by a thick mobile layer of salt. The differential movement of the salt is the cause of most of the structural features in the area. In detail, the area is extremely complex because of (1) the difficulty in correlating similar-appearing lithologic units of different ages, and (2) the maze of syndepositional (growth) faults throughout the entire area which have throws ranging from a few hundred to a few thousand feet. Statistical comparisons of producing trends and traps in Frio and younger sediments of south Louisiana can be accomplished realistically because of the above-mentioned repetitious deposition of similar-appearing biostratigraphic units in a basin which has had a relatively unchanging structural history.

The total estimated ultimate recovery from 690 fields in the area is 8,907,003,000 barrels of oil, 2,217,245,000 barrels of condensate, and 85,319,715,000,000 cu. ft. of gas. Using an economic value of one barrel of oil equal to 15,000 cu. ft. of gas, the total ultimate recovery of hydrocarbons is equivalent to 16,778,620,000 barrels of oil. The average hydrocarbon trap has 12,909,000 barrels of ultimately recoverable oil, 3,213,000 of ultimately recoverable condensate, and 123,652,000,000 cu. ft. of gas, or the equivalent of 24,317,000 barrels of hydrocarbons.

DISTRIBUTION OF HYDROCARBONS IN SOUTH LOUISIANA BY TYPES OF TRAPS

Hydrocarbons in Frio and younger sediments in south Louisiana, both onshore and offshore, are associated with six types of structural or combination structural-stratigraphic traps: (1) salt domes—intrusive salt penetrated by the drill; (2) circular or elongate domes, probably with deep-seated intrusive salt, but no salt drilled. This type of feature usually has a very strong associated gravity minimum; (3) anticlinal closures with associated regional deposition (growth) faults. These traps are closures along a regional, usually arcuate, approximately east-west-striking arch associated with a regional syndepositional (growth) fault. These arches seemed to be rim or hinge-line features associated with deposition in local basins. Evidence of relatively positive uplift is the reverse dip (usually toward the north) on the upthrown side of the depositional fault, indicating that the closure is not a result of faulting; (4) fault closures. In this type of trap, faulting is necessary for entrapment. Fault closure is formed where a fault cuts across the regional strike of the strata, or traverses a structural nose or ridge. These traps do not display local uplift on the upthrown side of the fault. Excluded from this type of trap are faulted outer flanks of localized uplifts; (5) closures on a regional structural nose. The origin of this type of structural trap may be attributed to many factors, including compaction above a sandstone lens, a residual high, a deep-seated salt uplift that has been quiescent for a long period of time, and others. Whatever the cause, relative uplift has not been sufficient to nullify the effect of regional tilting or downwarping. Consequently, the trap is mapped as a closure or local terracing on a regional structural nose; (6) stratigraphic traps on flanks of a structural nose or closure. In this type, the trap for the hydrocarbons on a particular structure (all horizons) is solely the result of sandstone pinchouts around the periphery of the structure. The apex of the structure, if it is a closure, is invariably barren of hydrocarbons.

DISTRIBUTION OF ULTIMATE RESERVES BY TYPES OF TRAPS

Salt domes account for 17.83% of the producing fields, 61.12% of the ultimately recoverable oil, 18.53% of the ultimately recoverable condensate, and 19.56% of the ultimately recoverable gas reserves. *Circular or elongate domes* account for 21.16% of the producing fields, 19.31% of the ultimate oil, 48.25% of the ultimate condensate, and 47.57% of the ultimate gas reserves. *Anticlinal closures with associated regional syndepositional faults* account for 20.73% of the producing fields, 14.08% of the ultimate oil, 22.05% of the ultimate condensate, and 22.50% of the ultimate gas reserves. *Fault closures* account for 31.59% of the producing fields, 3.62% of the ultimate oil, 9.54% of the ultimate condensate, and 8.56% of the ultimate gas reserves. *Closures on regional noses* account for 3.76% of the producing fields, 0.53% of the ultimate oil, 0.94% of the ultimate condensate, and 1.08% of the ultimate gas reserves. *Stratigraphic traps* on flanks of structural noses or closures account for 4.93% of the producing fields, 0.34% of the ultimate oil, 0.86% of the ultimate condensate, and 0.95% of the ultimate gas recovery.

COMPARISON OF AVERAGE ULTIMATE RESERVES OF EACH TYPE OF TRAP

The average salt dome has 44,984,000 barrels of ultimate oil, 3,340,000 barrels of ultimate condensate, and 135,694,000,000 cu. ft. ult. gas reserves, equivalent to 57,440,000 barrels of hydrocarbons. Circular or elongate domes have an average of 11,780,000 barrels of ultimate oil, 7,328,000 barrels of ultimate condensate, and 277,980,000,000 cu. ft. of ultimate gas reserves, or equivalent to 37,497,000 barrels of hydrocarbons. Anticlinal closures with syndepositional faults have an average of 8,772,000 barrels of ultimate oil, 3,420,000 barrels of ultimate condensate, and 134,240,000,000 cu. ft. of ultimate gas reserves, equivalent to 21,086,000 barrels of hydrocarbons. Fault closures have an average of 1,479,000 barrels of ultimate oil, 969,000 barrels of ultimate condensate, and 33,484,000,000 cu. ft. of ultimate gas reserves, equivalent to 4,619,000 barrels of hydrocarbons. Closures on regional noses have an average of 1,816,000 barrels of ultimate oil, 797,000 barrels of ultimate condensate, and 35,644,000,000 cu. ft. of ultimate gas reserves, equal to 4,996,000 barrels of hydrocarbons. Stratigraphic traps on flanks of structural noses or closures have an average of 882,000 barrels of ultimate oil, 450,000 barrels of ultimate condensate, and 18,282,000,000 cu. ft. of ultimate gas reserves, equivalent to 2,551,000 barrels of hydrocarbons.

OIL, CONDENSATE, AND GAS RESERVES RELATED TO ULTIMATE RESERVES OF ASSOCIATED TRAPS

With respect to total hydrocarbons for the average type of trap, the study discloses that for: (1) salt domes, 78.31% of the hydrocarbons will be oil, 5.82% condensate, and 15.87% gas; (2) circular or elongate domes will yield 31.42% oil, 19.54% condensate, and 49.04% gas; (3) anticlinal closures with associated syndepositional regional faults will yield 41.60% oil, 16.22% condensate, and 42.18% gas; (4) fault closures will yield 32.02% oil, 20.99% condensate, and 46.99% gas; (5) closures on regional noses will yield 36.36% oil, 15.94% condensate, and 47.70% gas; and (6) stratigraphic traps on flanks of structural noses or closures will yield 34.59% oil, 17.64% condensate, and 47.77% gas.

DISTRIBUTION OF RESERVES AND FREQUENCY OF SALT DOMES

Of 123 salt domes studied, 23 (18.70%) contain hydrocarbon reserves in the range of 0–5 MM barrels, 24 (19.51%) contain 5–20 MM barrels, 36 (29.27%) contain 20–50 MM barrels, 19 (15.45%) contain 50–100 MM barrels, and 21 (17.07%) contain 100 (+) MM barrels. Of the 146 circular or elongate domes, 56 (38.36%) contain 0–5 MM barrels, 36 (24.63%) contain 5–20 MM barrels, 25 (17.12%) contain 20–55 MM barrels, 17 (11.64%) contain 50–100 MM barrels, and 12 (8.22%) contain 100 (+) MM barrels. Of the 143 anticlinal closures, 67 (46.85%) contain 0–5 MM barrels, 38 (26.57%) contain 5–20 MM barrels, 20 (13.99%) contain 20–50 MM barrels, 12 (8.39%) contain 50–100 MM barrels, and 6 (4.20%) contain 100 (+) MM barrels. Of the 218 fault closures, 162 (74.31%) contain 0–5 MM barrels, 44 (20.18%) contain 5–20 MM barrels, 11 (5.05%) contain 20–50 MM barrels, and 1 (0.46%) contains 50–100 MM barrels. Of the 26 closures on regional noses, 23 (88.46%) contain 0–5 MM barrels, 1 (3.85%) contains 5–20 MM barrels, and 2 (7.69%) contain 20–50 MM barrels. Of the 34 stratigraphic traps on flanks of structural noses or closures, 30 (88.24%) contain 0–5 barrels, and 4 (11.76%) contain 5–20 MM barrels.

DISTRIBUTION OF ULTIMATE RESERVES BY PRODUCING TRENDS

Frio and younger sedimentary units in south Louisiana constitute one of the more prolific petroleum provinces of the world. Industry recognizes that it has one of the best exploration potentials on a per-dollar-invested basis of all domestic producing areas. Seven major producing trends are recognized. They are the Quaternary, Upper Fleming II, Upper Fleming I, Middle Fleming, Lower Fleming, Anahuac, and Frio.

Quaternary.—This is potentially a very good producing trend. As of January 1, 1964, only 18 fields (or 2.61% of the total fields) had been found in this trend and, relative to the more inland-situated trends, was sparsely drilled. Accelerated drilling has found several additional fields which were not included in this study. The trend contains 1.08% (96,040,000 bbls.) of the ultimate oil, 0.26% (5,453,000 bbls.) of ultimate condensate, and 0.54% (456,792 MMCF) of ultimate gas reserves. The average hydrocarbon trap contains 5,336,000 bbls. of oil, 303,000 bbls. of condensate, and 25,377 MMCF of gas.

Upper Fleming II.—This trend has 101 hydrocarbon traps representing 14.64% of the total fields in the area studied. It contains 42.76% (3,808,756,000 bbls.) of the ultimate oil, 21.30% (472,372,000 bbls.) of the ultimate condensate, and 20.92% (17,849,602 MMCF) of the ultimate gas reserves. The average hydrocarbon trap has 37,710,000 bbls. of oil, 4,677,000 bbls. of condensate, and 176,728 MMCF of gas reserves.

Upper Fleming I.—This trend has 124 producing traps representing 17.97% of the total fields. It contains 16.55% (1,474,336,000 bbls.) of ultimate oil, 13.25% (293,944,000 bbls.) of ultimate condensate, and 16.32% (13,920,092 MMCF) of gas and ultimate gas reserves. The average field contains 11,890,000 bbls. of oil, 2,371,000 bbls. of condensate, and 112,258 MMCF of gas.

Middle Fleming.—This trend has 70 producing traps representing 10.15% of the total fields. It contains 8.92% (794,144,000 bbls.) of ultimate oil, 10.88% (241,340,000 bbls.) of ultimate condensate, and 14.06% (11,997,595 MMCF) of ultimate gas reserves. The average field contains 11,345,000 bbls. of oil, 3,448,000 bbls. of condensate, and 171,394 MMCF ultimate gas reserves.

Lower Fleming.—This trend has 116 producing traps representing 16.81% of the total fields in the area. It contains 10.51% (936,365,000 bbls.) of ultimate oil, 25.14% (557,396,000 bbls.) of ultimate condensate, and 23.52% (20,067,689 MMCF) of ultimate gas reserves. The average field contains 8,072,000 bbls. of oil, 4,805,000 bbls. of condensate, and 172,997 MMCF ultimate gas reserves.

Anahuac.—This trend has 84 producing traps representing 12.17% of the total fields in the area. It contains 4.80% (427,113,000 bbls.) of ultimate oil, 5.32% (117,864,000 bbls.) of ultimate condensate, and 5,197,745 MMCF of ultimate gas reserves. The average field contains 5,085,000 bbls. of oil, 1,403,000 bbls. of condensate, and 61,877 MMCF of gas.

Frio.—This trend has 177 producing traps representing 25.65% of the producing fields of the area total. It contains 15.38% (1,370,249,000 bbls.) of ultimate oil, 23.85% (528,876,000 bbls.) of ultimate condensate, and 18.55% (15,830,200 MMCF) of ultimate gas reserves. The average field contains 7,742,000 bbls. of oil, 2,988,000 bbls. of condensate, and 89,436 MMCF of gas.

These data will aid in the future gross evaluation of individual prospects and assist in programming total exploration efforts.

12. WILLIAM F. TANNER, Florida State University, Tallahassee, Florida

ORIGIN OF GULF OF MEXICO

The Gulf of Mexico dates from approximately the Paleozoic-Mesozoic time boundary. From structural considerations, the hypothesis is proposed that the present Gulf is the result of a slowly widening rift, or tension gap, between North America (east of the Rocky Mountains) and Central America and the Caribbean block. Such an hypothesis, if correct, may explain several puzzling questions: (1) How should the southern Appalachians be extended southward from central Alabama? (2) What were the geologic and climatic conditions during deposition of Mesozoic evaporites in the Gulf region? (3) Why is the major delta complex of North America located in the vicinity of the Texas-Louisiana border? (4) What structural deformation is taking place in the area today?

A general program of investigation designed to test, or at least explore, the hypothesis is outlined.

13. C. H. MOORE, JR., Shell Development Company, Houston, Texas, AND K. G. MARTIN, Pan American Petroleum Corporation, New Orleans, Louisiana