system. Toward the south, the wedge thins to a few hundred feet where it is down-faulted below existing well control by post-embayment faulting. A series of paleostructural maps demonstrates that the basin subsided by northward rotational tilting into the boundary-fault system. Hydrocarbons accumulate where regional north dip is interrupted by local south dip or, as in most cases, where northward-plunging noses are terminated on the south by faulting. It is the thesis of this paper that regional north dip and thickening of rotational blocks into arcuate down-to-the-coast growth faults can be observed in all similar embayment-type structures, of which there are many in south Louisiana. The Houma embayment is at relatively shallow depths, and the presence of major hydrocarbon accumulations in the embayment wedge has encouraged a great amount of deep drilling. Information obtained from the deep drilling allows the structural history of the Houma embayment to be reconstructed accurately and used as a model for deep exploratory drilling in other areas.

19. WILLIAM R. PAINE, University of Southwestern Louisiana, Lafayette, La.

STRATIGRAPHY AND SEDIMENTATION OF HACKBERRY SHALE (MIDDLE OLIGOCENE) AND ASSOCIATED BEDS OF SOUTHWESTERN LOUISIANA

The Hackberry shale section of the middle part of the Frio Formation of southwestern Louisiana is one of the four deeper-water shale wedges in the post-Vicksburg Tertiary Gulf Coast section. The Hackberry section can be divided into two parts. The upper section ranges in thickness from zero to more than 3,000 ft., and consists predominantly of shale containing an outer-neritic (deep-water) assemblage; several thin, erratically distributed sandstone bodies are present. The lower zone ranges from zero to 700 ft. and consists mainly of sandstone.

To understand better the geological history of the Hackberry shale wedge, a discussion of the stratigraphy and structure of the Frio section has been included.

The complicated Frio stratigraphy of northern Jefferson Davis and Calcasieu Parishes is caused partly by a complex early (Frio) tectonic history and partly by variations in regional deposition of the Hackberry section. The geological history of the area is summarized as a sequence of eight steps. It should be emphasized that these eight stages are a *general* sequence of events, that they probably overlap one another, and that they may have occurred at slightly different times in different areas.

The steps are: (1) deposition of Vicksburg and *Textularia seligi* Zone of lower Frio; (2) development of lower unconformity (this may be a local unconformity); (3) deposition of lower Frio and Hartburg sequence; (4) uplift, folding, erosion, and development of pre-Hackberry unconformity; (5) tilting of unconformity surface and renewed erosion which formed channels; (6) deposition of basal Hackberry channel sandstone bodies; filling of channels which resulted in the development of a flat-surface sequence; (7) deposition of Hackberry with "arenaceous" fauna at the base; and (8) deposition of remainder of Frio.

The earlier structural movements formed folds and faults which then were truncated by regional erosion. On this eroded surface, large channels (600 ft. deep) were cut and later filled. The mechanism which cut and filled these channels is uncertain, but may be turbidity flows. The structural movements, history of erosion, and the complex stratigraphy of the Hackberry make exploration for Hackberry sandstone reservoirs a high-risk economic decision, but one which may pay high dividends.

20. PAUL S. FREEMAN, Union Oil Co. of California, New Orleans, La.

EXTRUSIVE SHALE MASSES: NEW GULF COAST EXPLORATION FRONTIER

Many Gulf Coast shale masses are extrusive deposits formed by the processes of "sedimentary volcanism." "Sedimentary volcanic" deposits have been recognized only recently in Tertiary strata of the Gulf Coast. Diagnostic evidence for this phenomenon is found at outcrops of the Catahoula Formation (middle Tertiary) in the south Texas counties of Live Oak, McMullen, Duval, and Webb. The absence of *active* "sedimentary volcanism" in the Gulf Coast and the difficulty of recognizing this phenomenon in ancient rocks are causes for a general omission of this subject from the American geologic literature; consequently, explorationists are overlooking diapiric and possibly extrusive origins for numerous Gulf Coast shale masses.

The ultimate relation of a buried extrusive shale mass to adjacent and overlying beds is determined by the amount of mudflow buildup and preservation during the time of deposition of the nearby normally deposited beds. If the sum of mudflow deposition (with accompanying erosion) greatly exceeds the sedimentation of the adjacent beds, large mudflow domes and ridges may form prominent topographic features. Conversely, if the rate of sedimentation of adjacent beds equals or exceeds that of the mudflow accumulation, an ill-defined mudflow facies is formed. Most thick, extrusive shale bodies probably are composite masses of both rapidly and sporadically extruded mudflows interfingered with normally deposited beds.

Growth of an extrusive dome is attained by a sequence of mudflows extruded from clusters of mudcones. Dips of mudflow layers increase as each succeeding layer is extruded and a domal topographic feature forms. Slopes of active mudcones are commonly 30–40°, depending on the mud viscosity; cones are known to exceed 1,500 ft. in height. Commonly, mudflows range in thickness from several inches to 50 ft. and extend as much as 2 mi. from their parent vent. Mudflow extrusions may take place simultaneously for many miles along a fault system. Active mudflow ridges 20 mi. long are known in West Pakistan. These flat-topped ridges are hundreds of feet thick and have steep sides with 40–70° slopes.

Erratic rocks commonly are brought up thousands of feet stratigraphically by mudflows. Erratics up to 3 ft. in maximum dimensions are common, and rarer occurrences of blocks with 50-ft. dimensions are known. Microfossils, thousands of feet out of place, occur in many places within extrusive mudflows or shale masses. Diagnostic evidence of diapiric clastic rocks includes: erratic fossils, churned shale pellets, gas bubbles, and disrupted rock frameworks.

Revised exploratory thinking is required to search successfully for and to recognize subsurface diapiric shale masses. Diapiric shale masses are formed in specific basins, along certain trends, and during favorable geologic times. Although intrusive shale plugs exhibit the same pronounced structures as salt plugs, buried extrusive shale masses are not associated generally with pronounced radial faulting, sharply upturned beds, or other commonly recognized structural attributes of intrusive masses.

Diapiric shales produce negative gravity anomalies because of low densities. Density logs show densities to be almost as low as salt. Low velocities (indicated by sonic logs) cause shale-mass structures to be mapped seismically as "lows" instead of "highs," unless correct velocity functions are used.

A common clue to subsurface diapiric masses is 0.5-ohm resistivity (IES log) caused mainly by high water content of the shale. Few correlations, if any, can be made in the diapiric mass. An abnormal microfaunal sequence is found in nearly every case, as is high-pressure shale gas. Because of their greater magnitude and distinguishable direction, mudflow dips within an extrusive mass can be recognized commonly by a dipmeter survey. Dips recorded within an intrusive shale plug or a "shale sheath" should be random in both magnitude and direction. Sidewall cores within a diapiric mass contain churned shale pellets and gas bubbles in the shale units and also bear disrupted sand-grain frameworks in the sandstone bodies.

Sandy, water-filled, gas-churned mudflows are high-porosity, low-permeability masses that serve as barriers to hydrocarbon migration. Intrusive structures must have had a timely injection in order to trap migrating hydrocarbons whereas extrusive shale masses are unusual barriers because the barrier is present before or during deposition of the adjacent beds.

Systematic recognition and delineation of extrusive shale masses in the Gulf Goast by both conventional and improved exploration methods will open new frontiers to Gulf Coast petroleum exploration.

21. LEONARD L. LIMES, Consultant, New Orleans, La.

PALEOCLIMATOLOGY: A NEW DIMENSION IN OIL EXPLORATION

As the global search for oil continues, new dimensions are needed to define areas with maximum potential for the accumulation of hydrocarbons.

Oil and gas are formed by organic material deposited under highly selective conditions. Climate affects all living organisms today, as it has throughout the geologic past. The climate at the time of deposition affects both the supply of oil-forming organisms and the associated sediments.

The climate of the earth depends on the heat received from the sun. Because the earth is nearly spherical, a temperature gradient must exist from the equator to the poles. These climatic zones control the environment of deposition and also the resulting oil accumulation.

Paleoclimatology, by revealing the distribution in space and time of its climates of the past, when correlated with known oil accumulation, provides a new dimension in oil exploration.

22. JACK MORELOCK AND WILLIAM R. BRYANT, Texas A. & M. University, College Station, Tex.

PHYSICAL PROPERTIES AND STABILITY OF CONTINENTAL-SLOPE DEPOSITS, NORTHWEST GULF OF MEXICO

Sediments from the continental slope and shelf edge in the northwest Gulf of Mexico were tested to determine their strength, stability, and consolidation characteristics. Consolidation tests for Sabine River delta samples and abyssal-plain samples were used in the interpretation of the shelf and slope samples. To approximate *in situ* conditions, a direct shear-test machine was used to measure shear strength, and an Anteus Back Pressure Consolidometer was used to determine consolidation.

The topography of this area has been attributed to local slumping of unconsolidated and unstable marine sediments. Although the Sabine River delta samples were underconsolidated, the continental-shelf and slope samples all were overconsolidated. The overconsolidation of these samples and the high values of shear strength are assumed to be the results of low deposition rates and incipient cementation of the mineral grains. Analysis of the void ratio *versus* log pressure consolidation curves indicated that the sediments were "sensitive" and, therefore, relatively undisturbed by the sampling process.

The shear strength ranged from 0.05 TSF for the upper 1 m. of sediment to more than 0.5 TSF for a simulated depth of 20 m. The shear-strength tests indicate that the slope sediments should be stable to great thicknesses on even higher slopes than exist in this area.

23. ALAN R. FERGUSON, Humble Oil and Refining Company, Houston, Tex.

FINDING ANCIENT STREAMS MEANS FINDING NEW RESERVES

(No abstract)

24. F. P. C. M. VAN MORKHOVEN, Shell Oil Company, Houston, Tex.

CONCEPT OF PALEOECOLOGY AND ITS PRACTICAL APPLICATION

Economic micropaleontology contributes to the search for hydrocarbons in two equally important ways: it provides the petroleum geologist with correlations and age determinations, and it is instrumental in the delimitation of fossil environments of deposition. This latter function involves the study of paleoecology, which deals with the relations between fossil taxa and (or) assemblages and their environments. Paleoecological studies depend heavily on a thorough knowledge of the ecology of living organisms, but the methods and terminologies used in each field are distinctly different. Because erroneous paleoecological information may influence seriously the geological interpretation of an area, a thorough knowledge of correct procedures and methods in paleoecology is essential, and the limitations in paleoecology also must be realized fully. These procedures are discussed and summarized briefly. Definitions are presented of a necessary set of pertinent ecological and paleoecological terms, some of which are introduced here for the first time. Certain erroneous procedures and misinterpretations common in applied paleoecological studies include the indiscriminate use of well cuttings, the evaluation of poor faunas, and the taxonomic misidentification of fossils.

25. GARRETT BRIGGS, Tulane University, New Orleans, La.

PRIMARY SEDIMENTARY STRUCTURES IN SEARCH FOR PETROLEUM

Several types of primary sedimentary structures have been used in determining the source and direction of transport of sediments. In the last 15 years, much attention has been given to the description and measurement of the azimuthal directions of paleocurrent features and to the preparation of paleocurrent maps to illustrate ancient current patterns. Aside from