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 up-