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Impact of Diagenesis on Exploration Strategy and Reservoir Management

Where is the best place to drill for hydrocarbons? This fundamental question has been answered differently ever since the search for petroleum began. For many years, the reply has been, "On the highest structural closure." More recently, a better understanding of sedimentary depositional environments has led to a general appreciation that stratigraphic pinch-outs are important places to test. Now, another answer can be proposed, "In diagenetic traps." A diagenetic trap is defined as one created by postdepositional modification of a portion of a sedimentary rock unit (e.g., a cementation barrier or a zone of secondary porosity).

The importance of diagenesis in the creation or destruction of porous reservoirs has been accepted, although not well understood, for several years. Its importance in forming hydrocarbon traps is only beginning to be appreciated. It is the goal of this paper to outline the most significant aspects of diagenesis with respect to hydrocarbon exploration and production, and to emphasize the importance of a diagenetic evaluation in any integrated exploration or production strategy.

On a basinal scale, we must consider the stratigraphy and tectonics not only in their traditional senses, but also in relation to the sources of subsurface water and the movement of that water throughout a basin. The regional water movement is important to both the migration of hydrocarbons and to diagenesis.

The proper timing of diagenetic cementation, porosity generation, and petroleum migration can result in the formation of diagenetic traps, in addition to the well-known structural and stratigraphic traps. To understand and to explore for such traps, we must understand the most typical cementation and porosity patterns in any given formation. This understanding should allow us to predict where a hydrocarbon column might be trapped against a cementation barrier or in secondary porosity.

An understanding of diagenesis allows us better to evaluate individual hydrocarbon plays. Diagenesis has a tremendous impact on the interpretation of wireline logs, especially resistivity/conductivity measurements. If we know the type and degree of diagenetic alterations in an area, we can determine whether apparently "wet" zones are truly wet or if they are actually productive. Careful evaluation of the diagenesis of a formation can aid with the interpretation of shows in nonproductive or marginally productive wells. The relation between pore geometry, degree of diagenesis, and location of hydrocarbon shows can potentially tell us the position of a hydrocarbon reservoir.

In reservoir management, the role of diagenesis begins with a basic understanding of the principal problems caused by pore heterogeneity and diagenetic minerals. Clay minerals, the most common diagenetic minerals, are largely responsible for formation damage. This damage arises when an incompatible fluid is introduced into a reservoir and interacts with the clays causing dissolution, disaggregation, or changes in clay surface properties (i.e., wettability). Different clays are susceptible to different types of formation damage. As a result, mud systems, completion fluids, and stimulation systems must be designed to prevent formation damage.

Reservoir management also requires an understanding of the reservoir heterogeneity. This heterogeneity can arise from variations in the environment in which the reservoir was deposited or from postdepositional alterations. Diagenetic analysis of the reservoir rock (i.e., thin sections, X-ray diffraction, SEM) is a must to properly evaluate spacial permeability variations. Once the significant rock property variables are identified, a reservoir can be divided into flow units and reservoir-rock types. Within each reservoir-rock type, the water-oil relative permeability characteristics will vary only slightly in contrast to large changes in air permeability. The benefits of such a reservoir study are: (1) ability to determine optimum flow rates for different wells during primary production, (2) optimum location of the injection-flow rates for injection wells during enhanced recovery operations, and (3) a factual base for further reservoir modeling.

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Energy Resources of Water-Bearing Geopressured Reservoirs

Estimates for the total gas resource in place in geopressured Tertiary sandstone reservoirs along the Gulf Coast range from 3,000 to 100,000 Tcf (85 to 2,832 trillion cu m). This wide range in estimates was the incentive for initiating an extensive research effort in Texas and Louisiana to obtain more reliable data on geologic, engineering, environmental, legal, and social aspects of developing the geopressured resource. These studies include investigation of the available heat and hydraulic energy present in these aquifers in addition to the methane. All resource calculations are based on interpretations of total sandstone thickness, lateral extent of reservoirs as defined by depositional and structural boundaries, porosity and permeability, reservoir drive, salinity, temperature, pressure, and methane solubility. Diverse estimates arise from inadequate knowledge concerning these critical parameters.

To obtain answers to the many questions, an extensive research program has been established at The University of Texas at Austin by the Bureau of Economic Geology and the Center for Energy Studies. The bureau has been conducting broad regional geologic studies (for resource assessment and geothermal fairway delineation) and detailed, site-specific studies (to identify potential test-well sites).

The Tertiary strata of the Texas Gulf Coast comprise a number of terrigenous depositional wedges which dip and thicken into the gulf basin. Some of the wedges, Wilcox, Vicksburg, and Frio, thicken abruptly in a downdip direction as a result of contemporaneous movement along growth faults which developed near the ancient shorelines. Thick sections of sand and mud accumulated on the down side of these growth faults; expulsion of water from these downfaulted sediments was impeded by the faults and, with increased burial and overburden, high fluid pressures characteristic of this geopressured zone developed. The lack of water circulation in these geopressured reservoirs resulted in the increase in the temperature gradient from approximately 1°F/100 ft (1.9°C/100 m) in the hydrostatic zone to 2°F/100 ft (3.7°C/100 m) in the geopressured zone.

The regional studies, followed by detailed local investigations, were pursued to delineate prospective areas for production of geopressured energy. A prospective area must meet the following minimum requirements: (1) reservoir volume of 3 cu mi (12.5 cu km), (2) minimum permeability of 20 md, and (3) fluid temperatures of 300°F (149°C). Several geothermal fairways were identified in the Frio Formation and Wilcox Group as a result of these studies. Only the Brazoria fairway, however, meets all of the specifications for a geothermal prospect in the Frio. The DeWitt fairway best meets the requirements in the Wilcox.

In the Brazoria fairway, located in Brazoria and Galveston Counties, Texas, several hundred feet of deltaic sandstones have fluid temperatures greater than 300°F (149°C). Permeabilities within these reservoirs are greater than 20 md; this high permeability is related to secondary leached porosity, which developed in the moderate to deep subsurface. The geothermal test well (Department of Energy and General Crude Oil 2 Pleasant Bayou) is located within the Austin Bayou prospect, Brazoria fairway. The reservoir consists of 250 to 300 ft (75 to 90 m) of sandstone with core permeabilities between 40 and 60 md and fluid temperatures from 300 to 350°F (149 to 177°C). The sandstone-shale section within the Austin Bayou area is represented by seven progradational sequences. Each sequence is characterized by low-porosity prodelta and distal delta-front shale and sandstone at the base grading to porous distributary-mouth bar and delta-plain sandstone and shale at the top. The older and deeper depositional sequences represent only the distal part of the lobate delta, and the later events represent the entire deltaic complex. The 2 Pleasant Bayou well has been completed to total depth of 16,500 ft (5,029 m) and testing will begin during the last half of 1979.

A proposed well in the DeWitt fairway, DeWitt County, Texas, will test the deep sandstone reservoirs in the lower part of the Wilcox Group. More than 300 ft (90 m) of deltaic sandstone is present within a fault block 3 mi (5 km) wide and 15 mi (24 km) long.

The Pleasant Bayou geopressured geothermal test well is expected to provide the first reliable data concerning many aspects of producing energy from the water in the geopressured zone. However, this single well will not answer all of the questions nor prove or disprove the feasibility; several additional wells are planned for both Texas and Louisiana.

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Geologic History of Deep Gulf of Mexico Basin

New multifold seismic reflection lines (approximately 15,000 nmi; 27,780 km) and ocean-bottom seismometer (OBS) refraction lines collected by The University of Texas Marine Science Institute, Galveston Geophysical Laboratory, in the deep Gulf of Mexico basin and its adjacent margins show a sedimentary section up to 10 km thick overlying an acoustic basement. The thick section is divided into two major depositional sequences separated by a prominent gulf-wide unconformity, tentatively assigned a middle Cretaceous (Cenomanian) age on the basis of seismic ties with core holes and comparison with global sea-level cycle charts.

Below the middle Cretaceous unconformity, the early geologic history of the gulf basin is complex. A rifted, block-faulted, and attenuated continental crust is inferred to underlie the deep gulf just north and west of the Campeche Scarp and eastward into the Straits of Florida area. A thick salt basin overlies this continental crust in the area north and west of the Campeche Scarp, where it forms a band of salt structure 50 to 100 km wide (Sigsbee salt dome province). Early deformation of the salt and the overlying thick Jurassic sedimentary section suggests a period of gravity sliding associated with early rapid subsidence of the basin.

Refraction data indicate that an oceanic crustal layer underlies the rest of the deep gulf basin. A Late Jurassic (post-salt) period of rapid seafloor spreading or oceanization probably provided a mechanism (thermal cooling) for the rapid Late Jurassic-Cretaceous subsidence.

A younger undeformed sequence of rocks onlaps and fills in on top of the oceanic crust, the outer basement high, and the early salt structures in the central deep gulf. This sequence represents the deeper water, offbank equivalent of the Late Jurassic-middle Cretaceous carbonate banks, shelves, and platforms that built up around the gulf basin as it subsided. The sequence thickens eastward to over 3 km beneath the Florida Scarp and Straits of Florida. Relief developed on these carbonate banks by middle Cretaceous time formed the proto-Florida and Campeche Straits. Location of the carbonate banks appears to be, at least in part, controlled by basement structure. Along the Florida and Campeche Scarps, there was a major middle Cretaceous shift from shallow- to deep-water sedimentation as the outer banks subsided.

The post-middle Cretaceous section in the deep Gulf is divided into five depositional sequences or seismic units, defined by major unconformities along the base of the northwestern Campeche Scarp and tentatively correlated with global unconformities and sea-level changes as follows: early Tertiary, middle Oligocene, late Miocene, and the Pliocene-Pleistocene boundary. The main source of sediment supply to the basin was on the west in Late Cretaceous-early Tertiary time, but shifted more to the north during the late Tertiary and culminated in deposition of the huge Pleistocene Mississippi fan.