9. H. B. EVANS, C. H. COTTERELL, H. SURKALO, AND W. L. KINNEY, Marathon Oil Company, Littleton, Colorado

LOGGING OBSERVATION WELLS IN AN *In Situ* COMBUSTION TEST

The Fry *In Situ* Combustion Test was conducted in a 3.3-ac. site in the Robinson Sandstone. Six observation wells were cored through the reservoir during various stages of expansion of the combustion front. These cores were sampled for porosity, permeability, grain density, formation factor, saturation exponent, residual fluids, and clay content. These data and core examinations show that the reservoir consists of three sandstone units, each having distinct reservoir properties.

Several combinations of logging devices were run in the observation wells to evaluate their effectiveness in tracking the front laterally and in estimating the degree of combustion vertically.

Gamma-ray-neutron, density, induction, and focused resistivity logs were run open-hole in two wells after combustion. Core, GRAPE,* and density-log porosity were compared with neutron-derived porosity. Both gas saturation and invaded-zone water saturations were calculated. Both methods outline the vertical variations in combustion. In two wells, no logs were run before casing was set. Conventional neutron logs were run through casing but it was necessary to construct departure curves for the conditions encountered. Gas saturations were calculated using the neutron-derived porosity values and core or GRAPE porosity values. This technique yields a qualitative picture of the vertical combustion distribution.

A small-diameter neutron device was run through tubing in one well. In this well, the device was run before the front reached the well and again after combustion occurred. This technique permits evaluation of the vertical extent of combustion using just the ratio of the two response curves.

Of the combinations listed, the neutron-density-focused-contact-resistivity program was most effective in open hole for quantitative determinations of the degree of vertical combustion. In cased holes, the neutron device was satisfactory for identifying the burned zone but the logging program was not designed for quantitative interpretation.

10. GEORGE S. GARBARINI, Sun Oil Company, Denver, Colorado, AND HARRY K. VEAL, Wolf Exploration Company, Denver, Colorado

POTENTIAL OF DENVER BASIN FOR DISPOSAL OF LIQUID WASTES

A reconnaissance subsurface geologic study has shown that three types of reservoirs are available for liquid waste disposal in the Denver basin. These are fractured Precambrian rocks, porous sandstone reservoirs, and thick shale suitable for disposal by the hydraulic-fracturing technique.

From 1962–1965, fractured Precambrian rocks at a depth of 12,000 ft. were being used as a disposal reservoir for toxic effluent produced at the Rocky Mountain Arsenal near Denver. The disposal well presently is shut in pending investigation of the possible relation between waste injection and Denver-area earthquakes which increased in frequency and magnitude during the injection period. Data points on the Precambrian of the Denver basin are sparse because only a few test wells reached it in search for oil and gas. Two borings on the Apishapa uplift indicate the presence of a good fractured Precambrian reservoir.

Porous sandstone reservoirs considered most favorable for waste disposal are the Permian Lyons Sandstone, the Triassic Dockum Sandstone, the Triassic-Jurassic Jelm-Entrada Sandstone, and sandstone bodies of the Cretaceous Dakota Group and Hygiene zone. The Lyons, Dockum, and Dakota are best suited for waste disposal in the southern part of the basin. Exploratory activity for oil and gas in this part of the basin has been very low in recent years, whereas activity is moderate to brisk in the central part of the basin where the Lyons and Dakota are prime drilling objectives. The Dockum Sandstone, potentially the best disposal reservoir volumetrically, is restricted to the southeast part of the basin. The Jelm-Entrada Sandstone and sandstone beds in the Hygiene zone offer potential disposal reservoirs along the heavily populated strip between Denver and Cheyenne.

Cretaceous marine black shale suitable for disposal by the hydraulic-fracturing technique is present everywhere in the basin. The shale crops out in large areas. Beneath the populous strip along the Front Range, the shale locally is covered by as much as 2,000 ft. of Late Cretaceous and Tertiary transitional and continental rocks.

11. HARRY PERRY, U. S. Bureau of Mines, Washington, D.C.

COAL IN LONG-RANGE ENERGY PATTERN OF UNITED STATES

Coal, in 1900, supplied nearly 90% of United States energy demand, but only 23% in 1965. Oil and gas, which together contributed 8% in 1900, accounted for 73% in 1965. Nuclear energy is expected to contribute 5% of demand in 1980 but fossil fuel production will continue to grow, with coal consumption increasing from 470 million tons in 1965 to 750 million tons in 1980; natural gas increasing from 16 Tcf. in 1965 to 25 Tcf. in 1980; and oil increasing from 4 billion bbls. in 1965 to 6.7 billion bbls. in 1980.

Despite the inroads of nuclear fuels, electricity generation will account almost entirely for the tonnage increase in coal consumption during this period. To secure this increase, research and development activities are being intensified to lower the cost of the delivered coal and to effect improvements in the combustion of coal in conventional thermal power stations. Ash deposits and corrosion are under intensive investigation, as are economical means for abating the emissions of sulfur and nitrogen compounds and fly ash that contribute to atmospheric pollution. Studies in progress on the location of power plants over the coal measures include means of economizing on water requirements and on long-distance power transmission. Coal-fired gas turbines and magneto-hydrodynamics are actively being investigated. Methods to improve the production of coke, char, and chemicals from coal carbonization are studied continuously.

The increasing consumption of oil and natural gas is expected to create pressure on domestic supply by 1980. The gap between supply and demand in the period beyond 1980 may be filled in part by substitution of electricity for gas and by synthetic oil and pipeline gas derived from coal or oil shale. Research activities

* Gamma-Ray Attenuation Porosity Evaluator.

in these fields have been in progress for more than 2 decades, and, with the aid of Federal funds, now are expanding at a rate designed to insure adequate supplies of oil and gas at low cost in the future. Synthetic oil processes under development include a variety of coal-hydrogenation and gas-synthesis processes. To supplement natural gas, several processes are being studied for pipeline gas production by means of hydrogasification, or by partial or total gasification of the coal and converting the synthesis gas to high-BTU pipeline gas.

In support of these and many other coal-utilization development activities, fundamental studies are conducted in many universities, research institutes, and private and government laboratories.

12. DONALD S. STONE, Chevron Oil Company, Denver, Colorado

Theory of Paleozoic Accumulation in Big Horn Basin, Wyoming

A theory of hydrocarbon accumulation has been developed to account for the interrelations of stratigraphy, structure, and fluid distribution in the Paleozoic oil fields of the Big Horn basin, Wyoming. The proposed theory explains the common oil-water contacts observed in the majority of the multi-zoned Paleozoic anticlinal fields and the associated correlation between vertical oil column, formational thickness in the crestal area, and number of Paleozoic formations which are productive of hydrocarbons. Similar chemical composition of all Paleozoic crude oils (despite selective alteration effects) and of the associated formation waters, severe vertical density stratification of fluids in the multi-zoned fields with large oil columns, and some unusual reservoir-pressure relations are considered in support of the concept of a "common pool state." Several exceptional fields are explained as the result of post-accumulation modification of an original common pool.

The primary conclusion of this study is that essentially all the commercial hydrocarbons trapped in Paleozoic and Triassic reservoirs in the Big Horn basin (and probably all of western Wyoming) were generated in the euxinic, dark-colored, organic-rich and phosphatic, fine-grained rocks of the marine facies of the Permian Phosphoria (Park City) Formation. Similar dark-colored "source rocks" are essentially absent from the rest of the Paleozoic section in the Big Horn basin. Also, important intersystemic unconformities representing long periods of erosion appear to have eliminated effectively all sub-Phosphoria formations (except, locally, the underlying Tensleep Sandstone) as possible storage reservoirs for Paleozoic oil that might have migrated before the Laramide orogeny. Thus, considerable importance is attributed to the fact that stratigraphic accumulations of commercial significance occur only in Phosphoria rocks, whereas all production from pre-Phosphoria formations is associated with structural closure.

The proposed theory states that, as a consequence of early generation and probable pre-Middle Jurassic flush migration within the Phosphoria marine facies, indigenous hydrocarbons became stored in the ideal primary stratigraphic trap of the western Wyoming shelf area. In the Big Horn basin area, this trap was created by facies change updip toward the east and south, and pinch-out and truncation of the widely distributed reservoir carbonates of the Phosphoria Formation toward the north. In addition, some hydrocarbons probably were expelled during early diagenesis into the underlying Tensleep Sandstone and, because of eastward lateral migration beyond the area covered by marine Phosphoria rocks, became caught mainly in several truncational subcrop traps at the Phosphoria-Tensleep unconformity.

As a result of the formation of many large anticlinal traps, and concomitant fracturing and faulting, during the Late Cretaceous-early Tertiary Laramide orogeny, the hydrocarbons held within the regional Phosphoria stratigraphic trap were released and spread into older Paleozoic reservoir rocks until they were adjusted fully to structure in common pools with common oil-water contacts. Segregation of an original common pool into several separate pools was accomplished in some exceptional fields of the basin by (1) selective hydrodynamic tilting within the Tensleep zone. (2) leakage or redistribution of fluids through fault zones, or (3) escape of hydrocarbons to the surface and inspissation resulting from the breaching of the original Triassic cap rock.

13. RAYMOND G. MARVIN, King Resources Company, Denver, Colorado

Facies Control of Oil Occurrence in Mannville Formation in Southern Alberta, Canada

The Early Cretaceous Mannville Formation and its equivalents are widely distributed in the subsurface in the Western Canada basin east of the Rocky Mountains. The formation is divided into the lower Mannville, which ranges from marine in the north to non-marine in the south, and the upper Mannville, which is a mixture of marine and non-marine sediments. The Mannville Formation is of considerable economic importance, because the sandstone reservoirs contain substantial oil and gas reserves. This paper deals primarily with that part of southern Alberta from the International boundary to Twp. 30.

The surface on which the Mannville Formation was deposited developed during a long period of erosion. An angular unconformity separates the Mannville from the underlying Mississippian and Jurassic. The pre-Cretaceous erosion surface, though of low relief, influenced considerably the depositional pattern of the Mannville. Variations in the thickness of the Mannville are primarily the result of irregularities on this surface.

The lower Mannville of southern Alberta was deposited under fluvial conditions in a well-developed drainage system in which the streams flowed toward the north. Lower Mannville sediments are confined mostly to the channels of this drainage system. Production is from porous and permeable sandstone bodies which were deposited as the streams migrated across broad floodplains.

Lower Mannville sediments filled most of the low areas on the erosion surface, thereby leveling the surface by late Mannville time. By the end of this time, the filling of the drainage system was complete and uppermost Mannville sediments were distributed across the entire area. The lowermost unit in the upper Mannville is the "Glauconitic sandstone," which appears to be non-marine in southernmost Alberta, but becomes marine toward the north. The "Glauconitic sandstone" contains most of the upper Mannville hydrocarbons. The remainder of the upper Mannville appears to be non-marine.