The most significant event since the discovery of oil in the Lower Kenai Conglomerate (Hemlock) at Swanson River was the discovery of multiple-pay sandstone beds in the Middle Kenai Formation. These sandstone beds furnish an additional objective and have higher porosity and permeability than the Lower Kenai Conglomerate. Gas pay zones have been found in both the Middle Kenai and Upper Kenai sandstone zones.

7. ROBERT M. WILLINGHAM AND JAMES A. McCALEB, Pan American Petroleum Corporation, Denver, Colorado

INFLUENCE OF GEOLOGICAL HETEROGENETIES ON SECONDARY RECOVERY FROM PERMIAN PHOSPHORIA RESERVOIR, COTTONWOOD CREEK FIELD, WYOMING

A thorough study was made of all available geologic and engineering data from the Cottonwood Creek Phosphoria dolomite reservoir. The data obtained correlate well with injection and production performance of secondary-recovery operations which at first were disappointing. Oriented fractures and other reservoir heterogeneities were identified; this information is being used to modify field operating practices in order to improve reservoir oil-recovery performance. The review also resulted in a better understanding of the reasons for the occurrence of such a prolific field.

The Cottonwood Creek field is on the east side of the Big Horn basin in northwestern Wyoming. It is on a west-southwest-dipping monoclinal surface along the southwest flank of Hidden Dome anticline. There is about 5,500 ft. of structural relief through the productive interval.

Isopachous-lithofacies studies indicate that the western half of Wyoming during the Permian was the site of a large arcuate marine embayment, with a westward connection to the Cordilleran miogeosyncline. Throughout the time of Phosphoria deposition the boundary between the carbonate facies and red shale-anhydrite facies fluctuated along a north-south zone in the eastern part of the Big Horn basin. Cottonwood Creek field is in the zone where the two facies intertongue. Reservoir zones interfinger with a red-shale anhydrite facies on the north, east, and southeast. The stratigraphic traps for hydrocarbons are the impervious strata of the redbed sequence where it grades into the carbonate facies. Within the productive area outlined by Cottonwood Creek field, upper Phosphoria shoaling and bioclastic thickening occurred together with a concomitant porosity increase within what generally is a dololutite facies.

The Ervay tongue ranges in thickness from 30 to 100 ft. and contains net pay intervals a few feet to 70 ft. thick. Porosity through this interval averages 10% and permeability averages 16 md. The increased porosity of the producing intervals is a result of the particulate nature of the carbonate material. This porosity is broken by the occurrence of discontinuous, irregular zones of dense dololutite. The producing interval contains oölites, lithoclasts, and residual fossil bioclasts. Vugs are numerous; some appear to be fossil molds. In general the rock appears to be related genetically to some form of organic accumulation, probably more biostromal than biohermal, associated with high-energy wave action; the high-energy environment periods alternated with periods of probable restricted hypersaline environment.

Cottonwood Creek field was discovered in 1953 and has produced more than 20 million bbls. of oil from 14,200 productive acres. Field development essentially was completed by 1958. During June, 1958, a crestal gas-injection program was begun to maintain reservoir pressure and increase ultimate oil recovery. Gas injection resulted in rapid movement of gas to producing wells and, in many wells, oil production rates declined. During the next 6 years, gas-injection operations were relocated in the reservoir three times to reduce the gas breakthrough to producing wells.

A crestal water-injection program was begun in 1959 and was expanded to mid-structure during 1962. In many places, injected water channeled rapidly to producing wells and resulted in decreased oil production. Some areas of the field responded to both gas- and water-injection programs. After injecting 22 million bbls. of water, it became evident that the reservoir was not responding to water injection in the desired manner.

To account for reservoir performance, all available geological, engineering, and production data were reviewed. These indicated that reservoir performance is dependent on both the primary (matrix) rock characteristics and a superimposed fracture system. The fracture system was the primary cause of poor injection performance.

The geologic conception of the reservoir was found to correlate well with field performance and resulted in a rational explanation of the poor secondary-recovery performance. A variety of methods was used to determine areal geological variations in the reservoir. The fracture system was delineated by core studies, bottom-hole pressure studies, injected-fluid movement, and a structural residual map. Good correlation was found to exist between the fracture system indicated by cores and the structural residual map. Matrix rock properties were determined by lithologic studies and log analyses.

Results from the study are being used to change field-operating practices extensively to improve reservoir performance.

8. IRVIN NIELSEN, Oil shale consultant, Glenwood Springs, Colorado

ECONOMICS OF OIL SHALE

Most shale-oil production cost estimates are between $1.25 and $2.10 per bbl. of pipeline crude produced from oil-shale deposits in northwest Colorado. Two companies have not released cost figures, but Union states that a 27½% depletion allowance is necessary before shale can be developed commercially. Other companies and organizations have conducted or are conducting shale-research projects, but none has published firm shale-oil cost estimates.

M. A. Lekas of the Atomic Energy Commission has speculated that costs of producing shale oil may be as low as $0.29/bbl. He maintains that these costs can be achieved by using nuclear blasts to create permeable, underground, *in situ* retorting chambers. The A.E.C. hopes to detonate such a test soon in oil shale.

The recent discoveries of valuable sodium minerals commingled with oil shale in the center of the basin may change significantly the economics of production.

The problems confronting this unborn industry are well known. The decision to start the industry should be based on the optimum combination of land, reserves, technology, operators, market, legal status, political, and governmental support. The decision can not be made unless these factors can be combined reasonably and with the knowledge that the conditions governing them are relatively stable.