areas, the conditions necessary for accumulation are present and the Devonian formations that produce elsewhere in the Williston basin extend into these areas. In south-central North Dakota, conditions necessary for stratigraphic traps are present where the Devonian Duperow and Birdbear formations have been truncated by erosion and are unconformably overlain by an updip seal in the form of lower Mississippian shale.

In north-central North Dakota (southwestern Bottineau County) conditions necessary for structural traps are present. In the 1½ miles between the Cardinal Keeler (NW., NW., sec. 1, T. 159 N., R. 82 W.) and the California Blanche Thompson (SW., SE., sec. 31, T. 160 N., R. 81 W.) removal of salt by solution from the Prairie Formation has resulted in collapse of the overlying sediments, creating a reversal in dip. It is probable that this is not an isolated situation along the edge of the salt and potentially extensive development of traps is indicated.

In southwestern North Dakota, Devonian sedimentation was influenced by the structure of the Cedar Creek anticline, causing the Winnipegosis, Prairie, Dawson Bay, and Souris River Formations to wedge out southwestward by non-deposition. The Duperow Formation is extensive, though thinned by erosion over the North Dakota part of the Cedar Creek anticline, and the overlying Birdbear and Three Forks formations have been removed by erosion. A thin shale, thought to be Mississippian in age, overlies these truncated formations. These conditions suggest that Devonian production from extensive stratigraphic traps may be found along the northeastern flanks of the Cedar Creek anticline in North Dakota.

19. ROBERT R. BERG, Embar Oil Company, Denver, Colorado

GEOLOGY OF MINNELUSA OIL IN NORTHEAST POWDER RIVER BASIN, WYOMING

Since 1957, with the opening of the Donkey Creek Minnelusa pool, 35 successful exploratory tests have proved the potential of upper Minnelusa (Permo-Pennsylvanian) sandstones. Oil is produced from structural, permeability, and unconformity traps, or from combinations of these. Trapping conditions are illustrated by the Robinson Ranch and Raven Creek fields.

Oil fields usually are associated with low-relief structures, and Minnelusa accumulations are accompanied by stratigraphic changes in younger beds of Permian, Triassic, and Jurassic age. The most obvious change occurs in the superjacent Opeche Shale. Updip thickening of the Opeche coincides with wedging-out of Minnelusa pay sandstones. Therefore, current geologic exploration relies largely on subsurface isopach mapping of the Opeche. Future exploration should consider other techniques of geologic interpretation, such as thickness changes in all younger units and use of the seismograph for stratigraphic as well as structural control.

More than 10 million barrels already have been produced from the Minnelusa. It is evident that many new fields are yet to be discovered. Average size of fields is small, but excellent reservoir sandstones may yield as much as one million barrels per well. Exploratory drilling, aided by moderate costs, will continue at a high level of activity for many years. Improved geological interpretation will help maintain an adequate success ratio.

20. CHARLES E. TRANTER, Mobil Oil Company, Casper

RAVEN CREEK FIELD, CAMPBELL COUNTY, WYOMING

Raven Creek field is located on the eastern side of the Powder River basin of Wyoming. Discovered in March, 1960, the field presently consists of 38 producing wells and 11 dry holes. Production is from the "B" sand unit of the upper member of the Minnelusa formation of Permo-Pennsylvanian age. Depth of production is about 8,300 feet. The trap is formed by updip truncation of the "B" sand unit against Opeche shale at the post-Minnelusa unconformity. Erosion of the productive sandstone appears to have been controlled by a resistant dolomite which overlies the "B" sand unit and by structural configuration present at the close of Minnelusa deposition. The trap is on the western flank of a pre-Opeche anticline, the axis of which has been breached by post-Minnelusa erosion. Basinward tilting has destroyed the anticlinal closure which probably existed and strengthened the stratigraphic closure along the western flank.

21. W.G.A. TECHNICAL STUDIES COMMITTEE, BERNARD E. WEICHMAN, Chairman, Superior Oil Company, Casper

RÉSUMÉ OF MINNELUSA GEOLOGY AND HISTORY OF MINNELUSA PLAY

The terminology of the Permo-Pennsylvanian rocks varies with different parts of the Powder River basin. The rocks are called the Minnelusa on the east, Hartville on the southeast, Casper on the south, and Tensleep, Amsden, and Darwin on the west. The sequence can be divided into three members, the Lower, Middle, and Upper, except for the Casper, where only the Middle and Upper are present. The Minnelusa is truncated northward from the central Powder River basin to a zero edge in Montana.

Compressive forces from the northeast and southwest produced a major northwest-southeast and a minor north-south trend of folding during late Minnelusa time. The north-south folds seem to be located over basement fault zones. Subsequent subaerial erosion breached the folds and truncated the upper Minnelusa beds. Following this the Opeche shale was deposited filling in the breaches and covering the Minnelusa beds.

The first commercial Minnelusa production was encountered in 1930 at the Mule Creek field from the Leo sands. In 1936 production was encountered in the Converse sand of the upper Minnelusa. Until recent years Minnelusa oil exploration was restricted to anticlinal structures with the Converse and Leo sands as objectives. The current active upper Minnelusa sand play began in 1957 at Donkey Creek and accelerated to its present activity in 1960 with the discovery of Raven Creek. Nine Minnelusa fields were discovered in 1961, ten in 1962, and five in the first two months of 1963, all from the Upper sandstone beds.

Five known types of traps are possible: (1) primarily structural; (2) structural and stratigraphic combined; (3) stratigraphic by buried topography; (4) stratigraphic by facies change; and (5) stratigraphic by regional truncation.

The primarily structural-type trap is evidenced at the Robinson Ranch field where 75 feet of closure exists on the Minnekahta.

The structural and stratigraphic combined-type trap is evidenced at Donkey Creek where there is 60 feet of closure on the Minnekahta. The "B" sand is a structural reservoir and the "A" sand is truncated through the center of the field, causing a stratigraphic pinch-out.

The buried topography type trap is evidenced at the Raven Creek field where the oil is located in the downdip ridge flanking a Minnelusa age structure, long since

altered into a gentle nose and sealed by a covering of Opeche shale.

The evidence for entrapment by regional truncation and facies change from sandstone into dolomite and anhydrite is not available for publication.

The recent approach to Minnelusa oil exploration is directed through seismic, magnetic, and subsurface structural mapping with Minnelusa age structures in mind. Isopaching the Opeche gives clues to buried topography. Detailed core and sample studies assist in locating facies changes and truncation as well as depositional character and trends of the reservoir rock. Holes based on little or no geology, drilled by independents and supported by majors, are effective in exploration. The discovery ratio of the eastern Powder River basin is 1:10.4 on wildcats and 1:3.49 for all wells. Average cost of a dry hole is $44,000, and $77,000 for a producer. Forty acres is the basic spacing and the average pay thickness is 25 feet. The gravity of the oil ranges from 12.5° to 37° API and is classed as a heavy, black, sour, intermediate base crude.

22. GEORGE DARROW, Consultant, Billings, Montana
ROBERT L. MARSH, Consultant, Billings

NEW FRONTIERS IN MONTANA EXPLORATION

Exploration and development in Montana during 1962 was particularly significant both in terms of successful wildcats which opened large new areas for future exploration, and field extensions which revealed unexpected economic potential in dormant field areas.

Two areas are discussed, the Williston basin in northeastern Montana and the Sweetgrass Hills province in northwestern Montana. A sequence of prolific pre-Mississippian Paleozoic discoveries in northwestern Montana since 1960 had earlier revived interest in this area. During 1962, exploration of this area was further stimulated by three widely separated new-field discoveries: Spring Lake, Lone Tree, and East Benrud, as well as successful development wells in Dwyer and Southwest Richey. McAlester Fuel's Spring Lake discovery, dually completed in the Devonian Nisku and the Ordovician Red River for a combined flow of 742 BOPD on choke was the most significant.

A regional structure map, field maps, and cross sections illustrate how these 1962 discoveries have broadened the areas of active exploration interest and extended the reservoir objectives throughout the entire lower Paleozoic section, with multiple pay zones occurring in carbonate reservoirs at depths ranging from 7,500 feet to 12,000 feet. The significance of the existing production for future exploration includes: (1) location of the new discoveries off of known major structures, (2) distance from established production, (3) characteristic, subdued low-relief structural expression with regional dips averaging 30 feet to 60 feet per mile, and productive closures typically 50 feet to 75 feet, and (4) influence of facies, pore-size distribution and hydrodynamic factors in controlling oil accumulation.

In the Sweetgrass Hills province of northwestern Montana, 1962 extensions to existing production in the Flat Coulee and Whitlash field areas have revealed better quality reservoirs than were previously known and opened new pools. Cross sections illustrate the Jurassic Swift and Lower Cretaceous Sunburst sandstone reservoirs in which this production occurs at depths of 2,800–3,000 feet. Field maps show the accumulations to be combination stratigraphic-structural traps located down-flank on known structures.

Numerous structural domes uplifted by deeply buried igneous intrusions, combined with rapid lateral variations in facies and porosity development in both Cretaceous and Jurassic reservoirs, holds forth the promise that many additional pools and fields will be found by future exploration in the Sweetgrass Hills province.

23. STANLEY D. CONRAD, Richfield Oil Corporation, Salt Lake City, Utah

EXPLORATION ACTIVITY AND OIL AND GAS DEVELOPMENT IN UTAH DURING 1962

Exploration activity continued at a moderate pace in Utah during 1962. The Paradox basin, which has been very active since the discovery of Aneth in 1956, had considerably less activity during the year. The Uinta basin, on the other hand, experienced a considerably accelerated rate of exploration, due largely to the completion of the Mountain Fuel Supply Company pipeline connecting many of the gas fields of the basin to the Wasatch Front markets.

Two rather insignificant new-field discoveries were made during the year in the southern end of the Paradox basin. Drilling of a few infield development wells and field extension wells continued in the greater Aneth area. The Ismay field received considerable drilling, extending the field south and southeast. The northern Paradox basin experienced some deep wildcat drilling in search of the Mississippian and deeper oil. All were unsuccessful. Three new discoveries were completed in the Paradox salt section in the general Big Flat area, indicating possible greater production from this stratigraphic interval. The Lisbon, Salt Wash, and Grassy Trail fields received some development drilling.

The Uinta Basin Uncompahgre area had at least ten discoveries or extensions of significance, five predominantly gas producers, and five oil. Two of these, the Phillips Flat Rock well No. 2 in sec. 30, T. 14 S., R. 20 E., and Pacific Natural Gas Exploration Moon Ridge No. 1, sec. 15, T. 16 S., R. 21 E., indicated possible important field discoveries. Formations from Tertiary Green River to Cretaceous Dakota shared in the discoveries. Development in the Red Wash, Chapita Wells, Ute Trail, and Rock House fields continued at a fair rate.

The emphasis of surface field work and geophysical work generally shifted west to the Wasatch Plateau, and Basin-and-Range areas, from the Paradox Basin, which has received most of the attention for the past few years. Considerable leasing took place in the Wasatch Plateau from the Clear Creek field south to the general Fish Lake area. Areas in the Basin-and-Range province, notably Box Elder and Iron Counties, experienced considerable leasing.

Oil production in 1962 was 31,104,169 barrels, a decline of approximately 813,000 barrels from 1961. Gas production totaled 72,516,409 MCF, an increase of nearly 14,000,000 MCF over 1961.

24. JOHN W. ROLD, California Oil Company, Denver, Colorado

HIGH-LIGHTS OF EXPLORATION AND DEVELOPMENT IN COLORADO AND WESTERN NEBRASKA, 1962

During 1962, 645 wells were drilled in western Nebraska, a 35 per cent decrease from the record year of 1961. The 381 exploratory wells resulted in 33 discoveries (success ratio of 8.7 per cent). Important developments in 1962 include the following: the expansion of the Cambridge arch productive area; the northward and northeastward spread of the search for Paleozoic oil into sparsely drilled north-central Nebraska; the rapid ex-