curvature (the second derivative of structure) can be expressed mathematically and it is found that permeability varies as the third power of curvature. A map of values of structural curvature shows a remarkable coincidence between areas of maximum curvature and areas of best productivity.

Volumetric considerations show that the quantities of oil being produced cannot be coming from the Sanish zone. It is concluded that the immediately overlying, highly petroliferous, Bakken Shale is the immediate as well as the ultimate source of this production. The role of the Sanish fracture system is primarily that of a gathering system for many increments of production in the Bakken.

The extremely high initial reservoir pressure indicates that the Sanish-Bakken accumulation is in an isolated, completely oil-saturated reservoir and, hence, is independent of structure in the normal sense. Similar accumulations should exist anywhere in the Williston basin where a permeable bed, of limited areal extent, is in direct contact with either of the Bakken shales.

15. STEVEN H. HARRIS, Harris, Brown and Klemer, Bismarck, North Dakota; COOPER B. LAND, JR., North American Royalties, Inc.; AND JOHN H. McKEEVER, Pan American Petroleum Corporation, Denver, Colorado

RELATION OF MISSION CANYON STRATIGRAPHY TO OIL PRODUCTION IN NORTH-CENTRAL NORTH DAKOTA

Nineteen oil fields in Renville and western Bottineau Counties, North Dakota, produce or have produced from the Mission Canyon (Mississippian) Formation. The production is primarily stratigraphic and occurs within five distinct and mappable sedimentary cycles herein named, in ascending order: Wayne beds, Glenburn beds, Mohall beds, Sherwood beds, and Bluell beds. Proper recognition and use of this cyclic framework are essential for interpreting the sedimentary history of the Mission Canyon. Structural, isopachous, and lithofacies studies can outline optimum areas to seek production within each unit.

16. ALAN R. HANSEN, Sun Oil Company, Billings, Montana

REEF TRENDS OF MISSISSIPPIAN RATCLIFFE ZONE, NORTHEASTERN MONTANA AND NORTHWESTERN NORTH DAKOTA

Algal pelletoid reef deposits comprise the oil-productive rocks of the Ratcliffe zone in the subject area. These rocks were formed in a moderate- to high-energy environment near the western limits of the Williston basin.

The reef trends were partially controlled by older faults or hinge lines which were re-activated during Ratcliffe time.

17. WILLIAM W. BALLARD, Balcron Oil Company, Billings, Montana

KIBBEY FORMATION OF MONTANA

Laboratory and field studies of the Kibbey Formation indicate that Kibbey rocks were deposited largely in shallow, marine, oxidizing water in the Big Snowy sea which extended across central Montana during Late Mississippian time. The Siouxia (Transcontinental) arch east of the depositional site supplied most of the detritus for the Kibbey rocks. The climate was semiarid. Relatively stable tectonic conditions with moderate to low relief prevailed in the source area throughout Kibbey deposition.

The present northern limit of Kibbey rocks is a result of post-Kibbey erosion; the southern limit, although locally determined by erosion, is essentially the depositional limit.

Sandstone beds of the Kibbey produce oil in Musselshell and McCone Counties, and produced for a short time in Roosevelt County, Montana. Kibbey rocks at *all three* productive localities appear to have been deposited under very similar environmental conditions and in essentially the same position with respect to the axis of the Big Snowy sea.

18. JAMES L. ALBRIGHT, Pubco Petroleum Corporation, Albuquerque, New Mexico

LISBON VALLEY ANTICLINE, PARADOX BASIN, UTAH—EXPLORATION AND DEVELOPMENT

In 1959, Pure Oil Company made sensational simultaneous discoveries of the first major oil and gas accumulations from the Mississippian in the Paradox fold and fault belt at Lisbon and McIntyre Canyon Units. These discoveries indicated that the tectonics of the pre-salt flowage structures in the province could and would be solved. A massive exploration program was launched, but during the intervening years, only three relatively minor discoveries have been made in pre-Pennsylvanian rocks. Two of these are associated with the Lisbon structural complex.

Similarities between the Persian salt anticlines and those of the Paradox basin had long been recognized and the idea of parallel, but offset, pre-salt structures was the basis on which large blocks were leased. Many operators were wary of seismic problems associated with salt flowage and(or) solution; however, Pure persevered and, in 1957, demonstrated at Big Flat field that seismic mapping was feasible and that the Mississippian could contain oil. This led to Pure's successful survey at Lisbon.

Drilling has shown that the thickened salt core of the Lisbon Valley surface anticline occupies the crestal graben of an offset-toward-the-southwest pre-salt anticline. Mississippian fault traps closed against salt have been found on the upthrown blocks on each side of the graben. Largest of these is the Lisbon Unit with 1,800 ft. of effective closure. In addition to the Mississippian, oil production has been obtained from the Devonian Ouray and McCracken but early promise of these formations as important objectives has not materialized.

One well, now abandoned, has produced oil from the Paradox salt.

Post-salt Pennsylvanian producing potential is indicated by two shut-in wells from multiple Hermosa sandstones on the downthrown block of the surface anticline which is closed against salt. Several wells within the Lisbon Unit have also tested "shows" of oil on drill-stem tests of the Ismay.

The Lisbon Valley-Dolores trend is only one of the five major salt flowage structural trends of the Paradox basin. Traps similar to those at Lisbon can be expected to be associated with other salt anticlines. A conservative estimate of the ultimate gross value of recoverable hydrocarbons from the Lisbon anticline is $100,000,000. Search for similar accumulations is indeed warranted!

19. JAMES A. PETERSON, University of Montana, Missoula, Montana.

STRATIGRAPHIC VS. STRUCTURAL CONTROLS ON HYDROCARBON ACCUMULATION IN ANETH AREA, PARADOX BASIN

Pennsylvanian oil and gas accumulations in the southern Paradox basin occur in carbonate mounds of

Des Moines age. Major oil production at Aneth, Ismay, Tohonadla, Gothic Mesa, Anido Creek, and other fields is from algal mounds elongated in a general northwest-southeast direction along the basin shelf. Carbonate reservoirs are closely associated with sapropelic black shales and evaporites, occurring in cyclic repetition in the shelf area and grading basinward into a predominantly salt section.

As far as can be determined all reservoirs are isolated bodies of porous carbonates, mostly limestone. About 30 oil and gas fields in Pennsylvanian rocks have been found in the Four Corners area, about half of which are classed as stratigraphic and the other half as either structural or structural-stratigraphic. In almost all cases it can be demonstrated that the accumulation would have developed even if no structural closure were present, although in many places the occurrence is localized by structural growth.

The Ismay and Aneth fields are selected as examples showing both stratigraphic and structural influence on accumulation, with the latter much more strongly influenced by stratigraphic boundaries than the former.

20. D. L. BAARS, Washington State University, Pullman, Washington

PRE-PENNSYLVANIAN PALEOTECTONICS—KEY TO BASIN EVOLUTION AND PETROLEUM OCCURRENCES IN PARADOX BASIN

A large northwest-trending fault block composed of late Precambrian through Mississippian rocks is exposed in the core of the San Juan Mountains near Silverton, Colorado. The fault block was formed prior to Ignacio (Late Cambrian) time when younger Precambrian quartzites were extensively down-faulted into the older Precambrian basement complex. The structure stood as a high topographic feature during Ignacio to Late Devonian time, but was largely buried by the upper Elbert Formation. Renewed activity occurred in Ouray (latest Devonian or earliest Mississippian) time, when tidal flats developed on the high flanks of the fault block while normal marine waters moved into the graben. The entire structure was high during the Early Mississippian, for the Leadville Formation is preserved only as tidal-flat dolomites and weathering residual blocks within the regolithic Molas Formation above. Pennsylvanian and later movement occurred along the graben, as Hermosa and Cutler strata are now involved in the graben.

With this paleotectonic feature as a model, other areas are more readily understood. A similar ancient fault block is present south of Ouray, Colorado, and extends northwest into the subsurface of the eastern Paradox basin. This structure joins a major northwest-trending pre-Pennsylvanian fault system that flanks each of the major salt anticlines which parallel the adjacent Uncompahgre uplift. Isopachous and lithofacies studies reveal that these structural lineaments were already present in Late Cambrian time, and actively controlled sedimentation through Mississippian time. It is possible that the closely related Uncompahgre uplift had a similar early history.

Pre-Pennsylvanian reservoir facies are best developed along the high flanks of the faults. Late Devonian McCracken sandstones occur in linear bars along the structures, and crinoidal biogenic banks, which are associated with all Leadville production, also occur on the shallower structural flanks. Where paleotectonic relief was too high, however, pre-Pennsylvanian rocks are missing either because of non-deposition or subsequent erosion.

The down-faulted paleotectonic troughs were the site of thick Pennsylvanian salt deposition. When Middle Pennsylvanian to Early Permian clastic wedges from the Uncompahgre uplift initiated salt flowage by differential loading, the fault blocks acted as buttresses which deflected the plastic salt upward. Consequently, the salt anticlines grew along the linear trends created by the Precambrian through Mississippian faults.

21. CHARLES S. TENNEY, Consultant, Casper, Wyoming

PERMO-PENNSYLVANIAN DEPOSITION IN WYOMING

Following truncation of the Mississippian sediments, much of the present State of Wyoming was tilted toward the south. Pennsylvanian seas advanced onto the shelf area of Wyoming both from the southwest and the southeast. In the southeastern portion of the State, a hinge-line developed in the vicinity of the tri-State area. This hinge-line separated a basin deep situated in eastern Colorado from a more stable, restricted bay or gulf which occupied much of eastern Wyoming. An entire sequence of Permo-Pennsylvanian sediments accumulated in this bay, and appears to have occupied an area very similar in outline to the present-day structural configuration of the Powder River basin.

22. DONALD E. LAWSON AND JORDAN R. SMITH, Forest Oil Corporation, Casper, Wyoming

PENNSYLVANIAN AND PERMIAN INFLUENCE ON TENSLEEP OIL TRAPS

Near the close of Desmoinesian time, regional uplift toward the west elevated the Tensleep of the Big Horn basin above sea-level. Broad, low-relief, northeast-trending folds developed during this orogenic uplift. Streams entrenched a well-developed drainage pattern on the exposed Tensleep surface and furnished sediment to the upper portion of the Minnelusa in the east and southeast. During Wolfcampian time, the Phosphoria sea transgressed the area and the incised stream channels were filled with shale and re-worked Tensleep sandstone; later Phosphoria deposition onlapped post-Tensleep hogbacks and low hills.

The majority of the oil that has been produced, and that will undoubtedly be produced, from the Tensleep has been from traps which are structurally controlled. However, accumulation in a significant number of these traps is the result partly or wholly of three stratigraphic variables; (1) an intra-formational change in permeability and(or) lithofacies providing a facies trap; (2) incised channeling with later infilling of basal Phosphoria shale providing a truncational subcrop trap; and (3) a combination of (1) and (2) above with later Laramide anticlinal folding superimposed on or near these primary traps, an effect which commonly causes the effect of tilted oil-water contacts. Either this type of tilt was not great enough to cause secondary migration farther into the fold or the downdip flow of ground water caused a "tar seal" to be formed at the oil-water interface and froze the oil in place.

There seems to be a depth-temperature-porosity relationship in the Tensleep. Thus far in the Big Horn basin, porosities are known to decrease progressively with increasing depth and temperature. Siliceous overgrowths form on the rims of the quartz grains, because of the increased compaction load and temperature, thereby reducing primary porosities. Ground water invading the Tensleep at shallower depths will also cause a similar phenomenon; therefore, the Tensleep will not always be porous even at shallow depths. Possibilities for finding adequate porosity at greater depths will be enhanced in