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 the future by exploring in those areas more favorable to the accumulation of oil in primary traps that have not been modified greatly by Laramide folding. Oil initially in place may retard secondary silicification of the Tensleep sandstones.

23. STANLEY M. EDWARDS, Continental Oil Company, Casper Wyoming

PERMO-PENNSYLVANIAN OIL TRAPS OF WESTERN POWDER RIVER BASIN OF WYOMING

Most oil traps on the western flank of the Powder River basin at first glance appear to be the result of Laramide anticlinal flexures. This, however, is not true of the fields producing from the Minnelusa Formation. Several Laramide anticlines have little or no production from the Minnelusa rocks. What, then, are the true methods and conditions of oil entrapment in the Minnelusa Formation?

The Minnelusa Formation in this paper includes those rocks below the Permian Goose Egg Formation and above the Mississippian Madison Formation. The Minnelusa Formation has been subdivided in this area into three members by previous authors. The three members are termed Upper, Middle, and Lower. The Upper Member is considered to be Wolfcampian in age and is probably the most important oil producer in the area. The Upper Member has been further subdivided into three rock units named, for simplicity, A, B, and C. A and B appear to be the most productive and also exhibit the greatest stratigraphic variations. Understanding the stratigraphic variations and their relationships to the Laramide structures can lead to a better development program of existing oil fields and further the exploratory efforts in little-drilled areas of the western Powder River basin.

24. JOHN P. WELDON, Tenneco Oil Company, Casper, Wyoming

DILLINGER RANCH FIELD, CAMPBELL COUNTY, WYOMING

Located in east-central Campbell County on the eastern flank of the Powder River basin, Wyoming, the Dillinger Ranch field produces oil from the "B" Sand section of the Permian part of the Minnelusa Formation. The field is defined by 17 wells and 5 dry holes. Total field reserves are estimated to be 5–10 million barrels of oil. The trap is formed by the intersection of a structural nose with an updip truncation of reservoir sandstone in a shale-filled channel.

Post-Minnelusa streams cut deeply into the formation and removed substantial portions of the alternating sandstone, carbonate, and anhydrite sequence. The Opeche Shale was then deposited over the entire basin flank, filling in the drainage valleys. Much later, the Laramide orogeny tilted the eastern flank of the basin toward the southwest. Migrating hydrocarbons were unable to move updip at those places where the reservoir sandstones encountered the impermeable shale seal in the channels. It is anticipated that many more fields will be discovered in the Minnelusa in similar stratigraphic traps along the eastern flank of the Powder River basin.

25. IRVIN KRANZLER, Consulting geologist, Billings, Montana

ORIGIN OF LOWER TYLER OIL IN CENTRAL MONTANA

A study of the Heath (Mississippian) and lower Tyler (Pennsylvanian) sediments of central Montana suggests a close relationship between the oil accumulations and the relative positions of the Heath Limestone and the lower Tyler sandstones. Reconstruction of the pre-Amsden structure and the Tyler-Heath paleogeology shows that the oil accumulations at Sumatra, Stensvad, Ivanhoe, Keg Coulee, Bascom, Melstone, and Big Wall fields occur where the paleo-structural position of the lower Tyler sandstones is updip from, and in direct contact with, the Heath Limestone. The foregoing relationships seem to be further supported by a study of Alice and Porcupine domes. These domes have barren sandstone reservoirs in excellent structural-stratigraphic traps. The paleo-structural attitude in the area of the domes was flat and the Heath Limestone apparently not well developed.

Application of these reservoir-source relationships should be useful in exploring for new oil reserves in the lower Tyler. The concept also may be applicable in other geologic provinces.

26. DONALD E. CAMPAU, Consulting geologist, Billings, Montana, AND BILLY B. LANE, State geologist, Billings, Montana

PROBLEMS OF CORRELATING PERMO-TRIASSIC REDBEDS IN WILLISTON BASIN

Correlation of Permo-Triassic redbeds in the Williston basin is relatively easy when a normal section is present; however, when some of the section is missing because of truncation or salt solution, correlation becomes very difficult, especially where redbeds of Triassic age rest on similar beds of Permian age or older. Poor samples and inadequate mechanical logs within the redbed section make correlation even more difficult. Correlation with the outcrop in the Black Hills is complicated further by the presence of massive salt beds in the subsurface that are not present on the surface.

Salt solution is common and, where faulting and fracturing are known to exist, appears to be related to paleostructures. Failure to recognize this phenomenon could result in misinterpretation of structure, especially when the seismic method is used.

27. A. SATERDAL, Independent petroleum geologist, Denver, Colorado

LOWER CRETACEOUS OIL FIELDS OF NORTHERN SWEETGRASS ARCH, MONTANA

An Early Cretaceous age is considered to be most probable for the group of productive sandstones which are found in the northern Sweetgrass arch and which extend from a basal unit (Cut Bank), that lies directly on the deeply eroded Jurassic Rierdon Shale, upward 200 ft. in the section to include the main productive sandstones at Fred and George Creek and Flat Coulee fields (possible "Moulton" stratigraphic equivalents). Areas of substantial sandstone development, having good reservoir characteristics and oil "shows," occur at stratigraphic positions intermediate between the Cut Bank and "Moulton" and can be found at other localities on the northern Sweetgrass arch.

All of these sandstones have a general relationship with the underlying erosional surface on the top of the Jurassic Rierdon, and thus are indirectly related to each other.

Study of the oil and gas fields from the Lower Cretaceous of the northern Sweetgrass arch is confined for practical reasons to the more recently discovered fields for which electric logs are available. The three most important of these fields are Fred and George Creek, Flat Coulee, and Red Creek. Each produces from basal or near-basal Cretaceous sandstones but differs in detail