the seismograph has proved to be an invaluable tool in describing potential potash reserves by outlining areas of salt removal. Gravity and magnetic control may help to unveil some lower Paleozoic structural anomalies. The Nelson River gravity "high" appears to suggest the position of the boundary between the Churchill and Superior Precambrian provinces in southeastern Saskatchewan and, therefore, outlines a very interesting trend with respect to lower Paleozoic prospects.

12. LLEWELYN JONES, Geological Sciences Branch, Saskatchewan Department of Mineral Resources, Regina, Saskatchewan

SEDIMENTATION AND ECONOMIC PROSPECTS OF MIDDLE DEVONIAN WINNIPEGOSIS FORMATION OF SASKATCHEWAN

The Middle Devonian Winnipegosis Formation of Saskatchewan is divisible into upper and lower members on the basis of a regionally developed argillaceous interval which forms the uppermost part of the lower member.

The lower member consists of a regionally dolomitized marine carbonate of relatively constant thickness and lithology, attaining a maximum observed thickness of 54 ft. The upper member is a varied marine carbonate sequence, with three major facies developments. In the southwest lies a wedge of lithologically relatively consistent carbonates, reaching a maximum thickness of about 130 ft. along a northwest-trending axis extending through Weyburn and Elbow. In the north and east, bioclastic-pelletoidal carbonate banks with true reef intervals (up to 345 ft. thick), and finely laminated, interbank carbonates (up to 68 ft. thick) occur.

The lower member was laid down in a broad epicontinental sea. The relatively shallow, open marine conditions culminated on two occasions in basin-wide, reducing, lagoonal conditions, evidenced by the medial and upper very bituminous argillaceous intervals containing impoverished faunas. The upper member appears to have been deposited in a shallow shelving sea which deepened toward the northeast. Using a regionally developed *Amphipora* zone as a datum, three pre-*Amphipora* tectonic-sedimentational regions are discernible: in the southwest, the Elbow-Weyburn basin, subsiding relatively rapidly to accommodate thick, shallow-water carbonates; in the north and east, the comparatively stable Saskatoon shelf, with thin laminated carbonates and basal carbonates of the bank sediments; and the more rapidly subsiding Meadow Lake-Sayese basin complex, with similar sediments, except that bank sedimentation was further advanced. In post-*Amphipora* time, subsidence continued in the north, accelerated in the shelf area to accommodate thick bank accumulations, whereas, in the southwestern basin, carbonate deposition was almost complete.

Although no commercial quantities of oil or gas have been found in Saskatchewan, production of oil from the Winnipegosis in the Outlook and Redstone fields of northeastern Montana is encouraging. The occurrence of oil and gas "shows" in some drill-stem tests and of oil staining in the Winnipegosis Formation in Saskatchewan offers further encouragement, especially in the Elbow-Weyburn basin, which is a northwestern extension of the oil-producing facies of northeastern Montana. The presence in the southwestern basin of permeability traps resulting from differential dolomitization and recrystallization, and. in the north and east, of important thickening in short distances, associated with variably porous bank carbonates, together with the widespread development of an excellent top seal in the form of the Prairie Evaporite salt or carbonate-anhydrite sequences, provide excellent conditions for the entrapment of hydrocarbons.

13. FRANK A. RADELLA, Consulting geologist, Billings, Montana

NISKU OF NORTHEASTERN MONTANA WITH SPECIAL REFERENCE TO TULE CREEK AREA, ROOSEVELT COUNTY, MONTANA

Oil accumulations of the Tule Creek area, that are found in the Devonian Nisku Formation, are a result of structural and stratigraphic conditions. Present-day productive structures have about 50 ft. of closure. These structures occur in an area of favorable Nisku patch-reef environment that was subjected to secondary dolomitization.

The Nisku of the Tule Creek field consists of anhydrite, limestone, and dolomite and averages 81 ft. in thickness. The upper one-third of the formation is primarily anhydrite and the lower two-thirds are dolomite. Some limestone always is present in the middle of the anhydrite unit. In the lower two-thirds, where found off structure, the unit is non-productive and(or) out of the favorable facies.

Oil production is from vuggy and intercrystalline porosity and permeability developed by secondary dolomitization. Occasional high-angle fractures contribute only slightly to the over-all reservoir productivity. Abundant relict *Amphipora* and lesser amounts of algae are apparent in the dolomite and appear to be the primary host for the dolomitization process. Only minor amounts of *Amphipora* are found in the non-dolomitized carbonate strata.

On structure, oil-productive dolomite consists of large-sized rhombohedral crystals oriented randomly or in point-to-point contact, improving the primary porosity and creating excellent permeability. The lesser dolomitized, non-productive, off-structure Nisku exhibits good apparent log porosity but very low actual effective permeability. These off-structure dolomites are finer-grained, slightly to moderately calcareous, and have a face-to-face crystal orientation.

The favorable patch-reef facies of the Nisku Formation is controlled by environment and trends locally in a southwest-northeast direction.

Structural closures that occur in the favorable facies area contain reservoir rocks with excellent porosity and permeability.

With a 24-ft.-thick anhydrite bed above the "pay" zone, a 10-ft.-thick dense anhydritic shale (Ireton Member) below, and a lack of extensive fracturing, the Nisku is postulated to be its own source rock.

14. GEORGE H. MURRAY, JR., Consulting geologist, Billings, Montana

QUANTITATIVE FRACTURE STUDY—SANISH POOL, MCKENZIE COUNTY, NORTH DAKOTA

The Sanish pool of the Antelope field has a number of unusual facets which make it almost unique in the Williston basin. Some of these are: (1) high productivity of a number of wells from a nebulous, ill-defined reservoir; (2) association with the steepest dip in the central portion of the basin; (3) very high initial reservoir pressure; and (4) almost complete absence of water production.

Analysis of these factors indicates that Sanish productivity is a function of tension fracturing associated with the relatively sharp Antelope structure. A relationship between fracture permeability and structural

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