NORTH DAKOTA GEOLOGICAL SURVEY

Wilson M. Laird, State Geologist

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NORTH DAKOTA'S NESSON ANTICLINE

by

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A 21-year search for oil ended in 1951. Now additional important fields are focusing attention on . . .

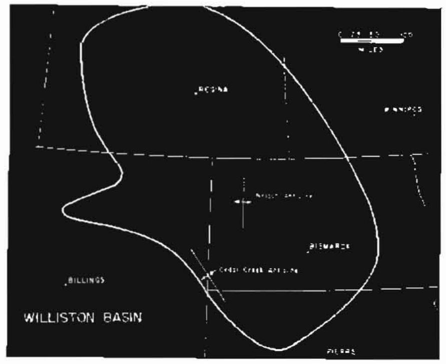

FIGURE 1—Location of the Nesson anticline in the Williston Basin.

North Dakota's Nesson Anticline

Here is a discussion of the geologic and production characteristics of the area and a detailed description of operating problems.

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THE NESSON ANTICLINE is a geologic freak subdividing the vast Williston Basin. Exploratory effort seeking petroleum reserves has combed the surface and subsurface secrets of this structure for the past three decades. Yet, production in commercial quantities was not uncovered until 1952.

The structure extends roughly in a north-south direction from the Canadian border to the Little Missouri River, although the northern part of the structure is not known from surface indications.

From the Canadian border to the Missouri River, the area is a typical glaciated plain on which dry land agriculture is the principal industry. In the immediate vicinity of the Missouri River and the Little Missouri River, the topography becomes more rugged with sharp ravines cutting into the plateau surface. In this region, numerous buttes stand out prominently above the general level of the terrain and grazing is the primary industry.

The producing area of the Nesson anticline extends to both sides of the Missouri River. The only crossing available to vehicles are the bridges at Sanish and 50 miles to the west at Williston.

The Missouri river cuts through the Nesson anticline about 30 miles east of Williston. The river being the principal route of trappers and explorers, it is probable that the gentle arching of the sedimentary beds along the north bank was noticed in the early 1800's. It was not until 1920 that a well was drilled in the Williston area, seeking oil and/or gas. This early well was drilled by the Pioneer Oil and Gas Company about two miles southeast of Williston. It was completed in 1920 as a dry hole and little else is known about it.

In 1935 and 1938 two more wells were drilled within a half mile of each other about 1½ miles northeast of the town of Hofflund. The first well was the Big Viking Kamp 1, and the second was the California, Kamp 1. Although both wells were abandoned as dry holes, they are only a mile from present production and are direct offsets to the field boundaries of the present Capa field. The earlier well did not penetrate deep enough to test the Madison formation which is now the principal producing horizon.

The Kamp well of the California Company was drilled in 1938 to 10,281 feet before finally being abandoned due to stuck drill pipe. The geologists, at that time, were unable to correlate the formations in the lower half of the hole and it was not until several years later that these formations were identified positively. It is possible that the well could have yielded commercial production from the Madison had not an unfortunate chain of circumstances occurred. When the well reached the depth at which it is possible that oil might have been encountered, the crew was engaged in changing from rock bit to core bit and jetting pits. The samples from this interval are noted as "badly contaminated."

On the third of September, 1950, the Amerada Petroleum Corporation spudded its Number 1 Clarence Iverson, five miles north and 2½ miles east

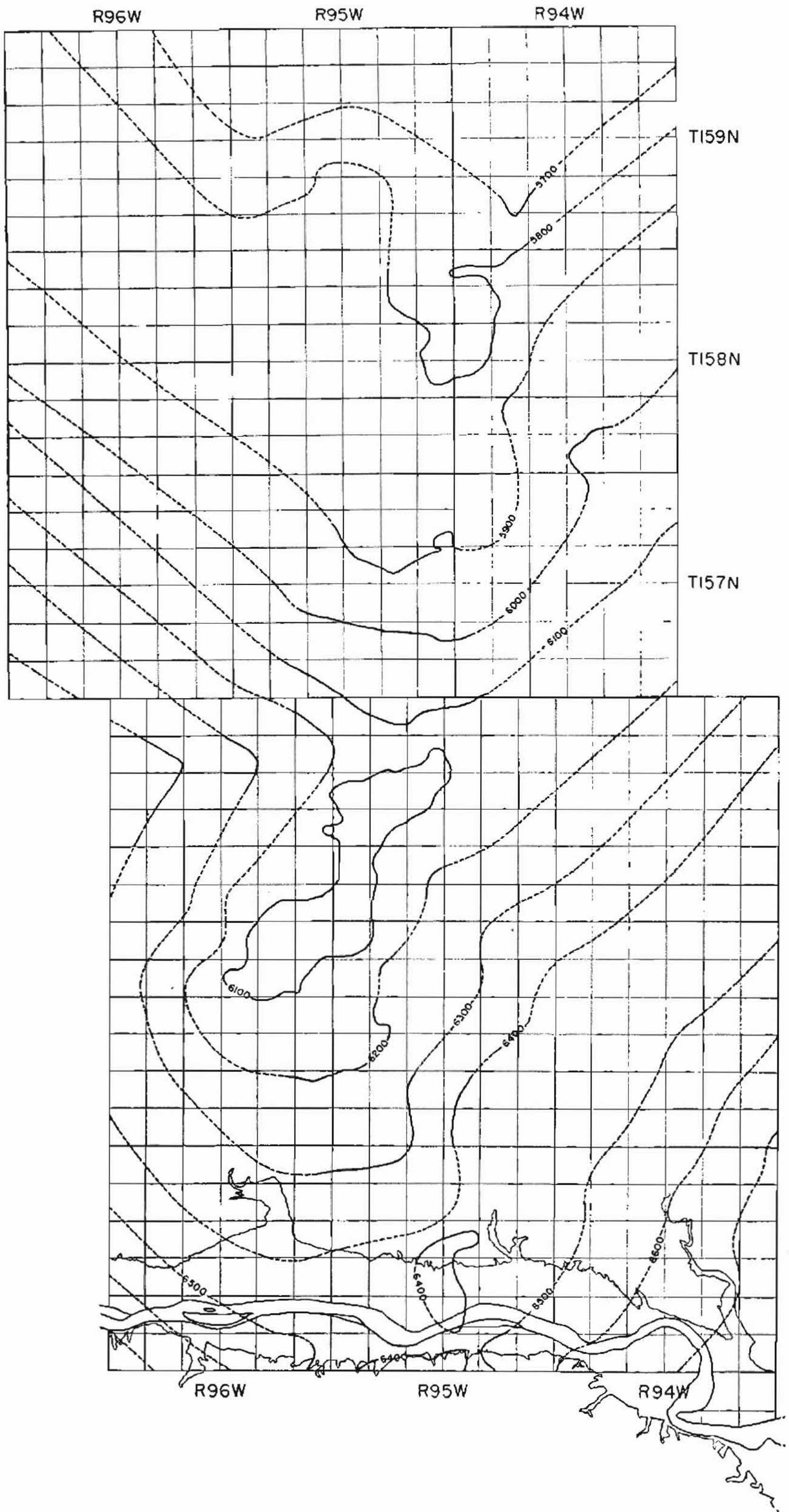

FIGURE 2—Structure on top of the main porosity, north half.

of the 1938 well. The well was drilled to 11,744 feet and casing was set. Several intervals were perforated, tested, and plugged before oil was recovered from perforations at 11,630 to 11,660 feet in the Silurian. The well flowed 307 barrels of oil and 25 barrels of water in 17 hours ending at 5 a.m. April 5, 1951.

Drilling was resumed and the well was deepened to 11,955 feet. It was plugged back and perforated in the Devonian from 10,490 to 10,530 feet and the rig was released July 22, 1951. Initial production from the Devonian was 290 barrels of oil during the first 24 hours.

The first production from the Iverson well totaled 3092 barrels of oil from the Silurian. After plugging back, the well produced 17,408 barrels of oil from the Duperow (Devonian). In December, 1951, the Iverson well was plugged back and recompleted in the Mission Canyon formation of the Madison group for initial production of 677 barrels of oil per day.

The Amerada Bakken 1 was spudded in June, 1951, about 12 miles north of the Iverson and drilled to 13,709 feet. Casing was run and several intervals were tested. The well was completed as a producer through perforations in the Mission Canyon from 8312 to 8350 feet on April 14, 1952.

The field discovered by the Clarence Iverson was named the Beaver Lodge, although the first production from the Beaver Lodge-Madison pool was obtained from the Palmer Dilland 1. The Bakken well is considered the discovery well for the Tioga field.

Development continued rapidly in these new fields and new discoveries were made during 1952, when the Charlson and Croff fields were opened south of the Missouri river. The Croff field was at the southern end of the anticline about eight miles north of the Little Missouri river. In 1953, the East Tioga field found production on the east flank of the anticline and the Hofflund field was opened southeast of Beaver Lodge. The McGregor field on the west flank was opened in 1954, and the Capa field was discovered in 1953 to the south of the Beaver Lodge, and west of the Hofflund field.

At the present time and under current orders of the North Dakota State Industrial Commission, the oil and gas regulatory authority for the state, the Beaver Lodge and Tioga-Madison pools are almost completely developed.

Regional Geology. The Nesson anticline is a structure which has been known for many years. From the beginning of history probably many of the early travellers crossing this territory looked at this area without knowing the exact meaning of this large fold. It was first mapped geologically by Collier in 1918 and his report was published as one of the Bulletins of the U. S. Geological Survey.

It will be noted by looking at the index map of the area (Figure 1) that the Nesson anticline is located in the approximate center of the Williston Basin. The structure is more or less isolated and not apparently related to any other fold in the basin. Its structural trend diverges from the nearest large structure in the general area, namely the Cedar Creek anticline. It will be noted that the Cedar Creek anticline trend is in a northwest-southeast direction whereas the trend of the Nesson anticline is almost due north and south. Undoubtedly, there is some genetic relationship between this fold and other folds in and on the margins of this basin but as yet evidence is not sufficient to make a positive statement as to this relationship. As more geophysical work is done and more wells are drilled bringing more information to light, more accurate hypotheses as to the relationship of the various folds in the basin can be made.

The Nesson anticline is a rather low, broad regional type of structure with a closure of probably less than 100 feet. On this structure, however, are smaller domes which are somewhat higher structurally. (See Figure 2.)

When the structure contours are drawn on various horizons in the area of the Nesson anticline, it has been found that there is a migration of the axis of the fold with depth. The structure on the Greenhorn formation in the Cretaceous section is approximately a mile east of the structure on top of the pay horizon in the Mission Canyon formation. Insufficient evidence is at hand to indicate whether the axes on the lower formations particularly in the Devonian and Silurian diverge from the position of the Mission Canyon axis. However, from the few wells which had been drilled in the area, it is suggested that the top of the structure on the Devonian and Silurian may even be farther west than that of the top of the Madison.

Unpublished geophysical work done by the North Dakota Geological Survey would suggest that there is considerable relationship between the magnetic highs and the actual structural highs on the top of the pay horizon. There is a marked correspondence between the magnetic high and the Charlson field as well as a correspondence between the magnetic high and the Capa field. However, in the case of the Beaver Lodge field, the magnetic high is somewhat to the west of the structural high, but the magnetic axis then trends eastward and the magnetic high more or less coincides with the structural high in the Tioga field.

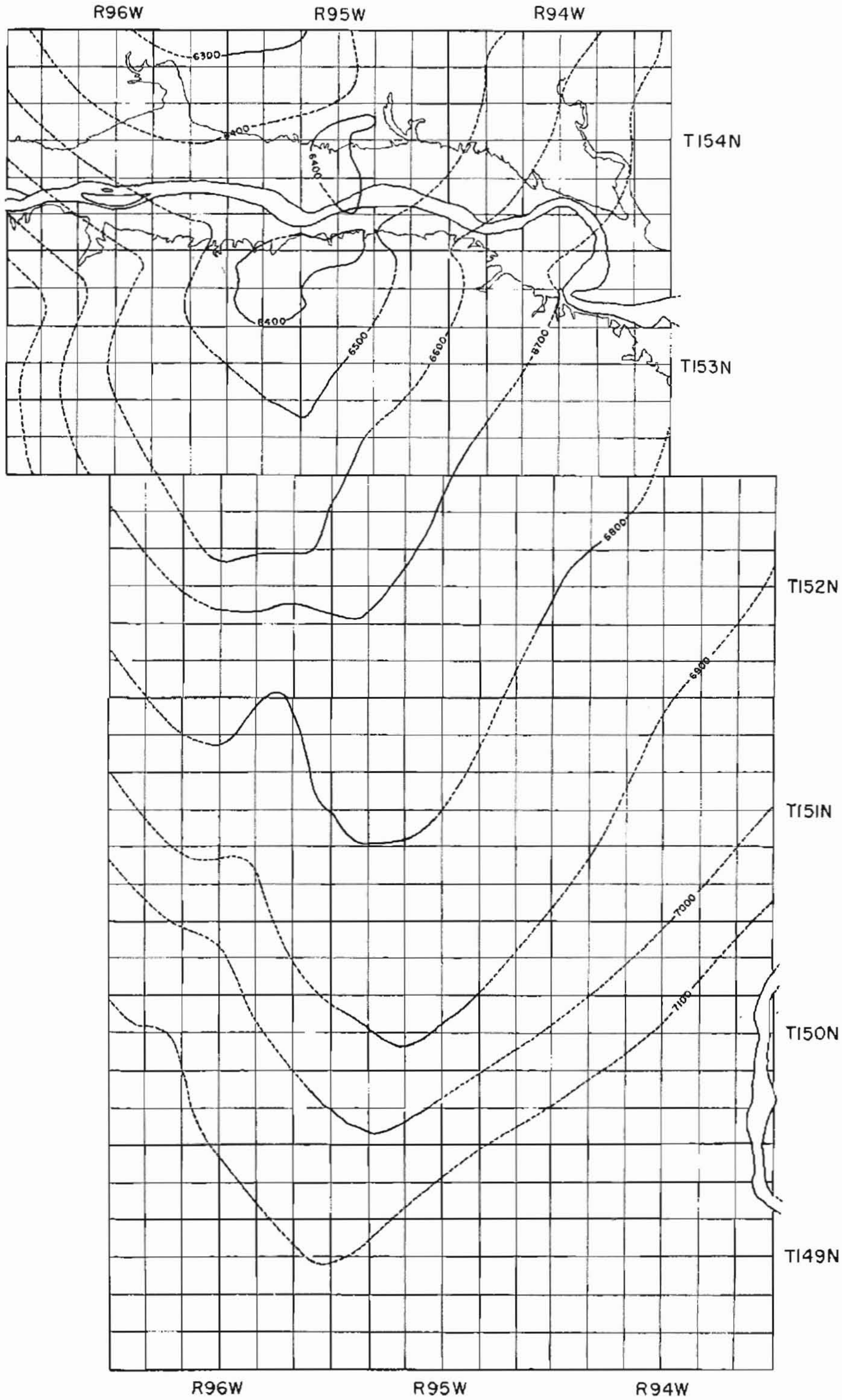

FIGURE 2a—Structure on top of the main porosity, south half.

The origin of the folds must be considered in any structural picture of this area. It has been suggested that the Nesson anticline is due to vertical movements in the basement rock. The movements have been apparently intermittent over much of Paleozoic and subsequent time. Isopach maps of the various formations in the area suggest that this movement started probably sometime in the latter part of Ordovician time and became more active as time progressed. Probably, it was most active at the end of the Paleozoic.

It is felt that this is not a simple fault arching the beds above it, allowing the beds to be draped over in a normal plains type fold. Very likely as the structure was uplifted intermittently, other faults, particularly

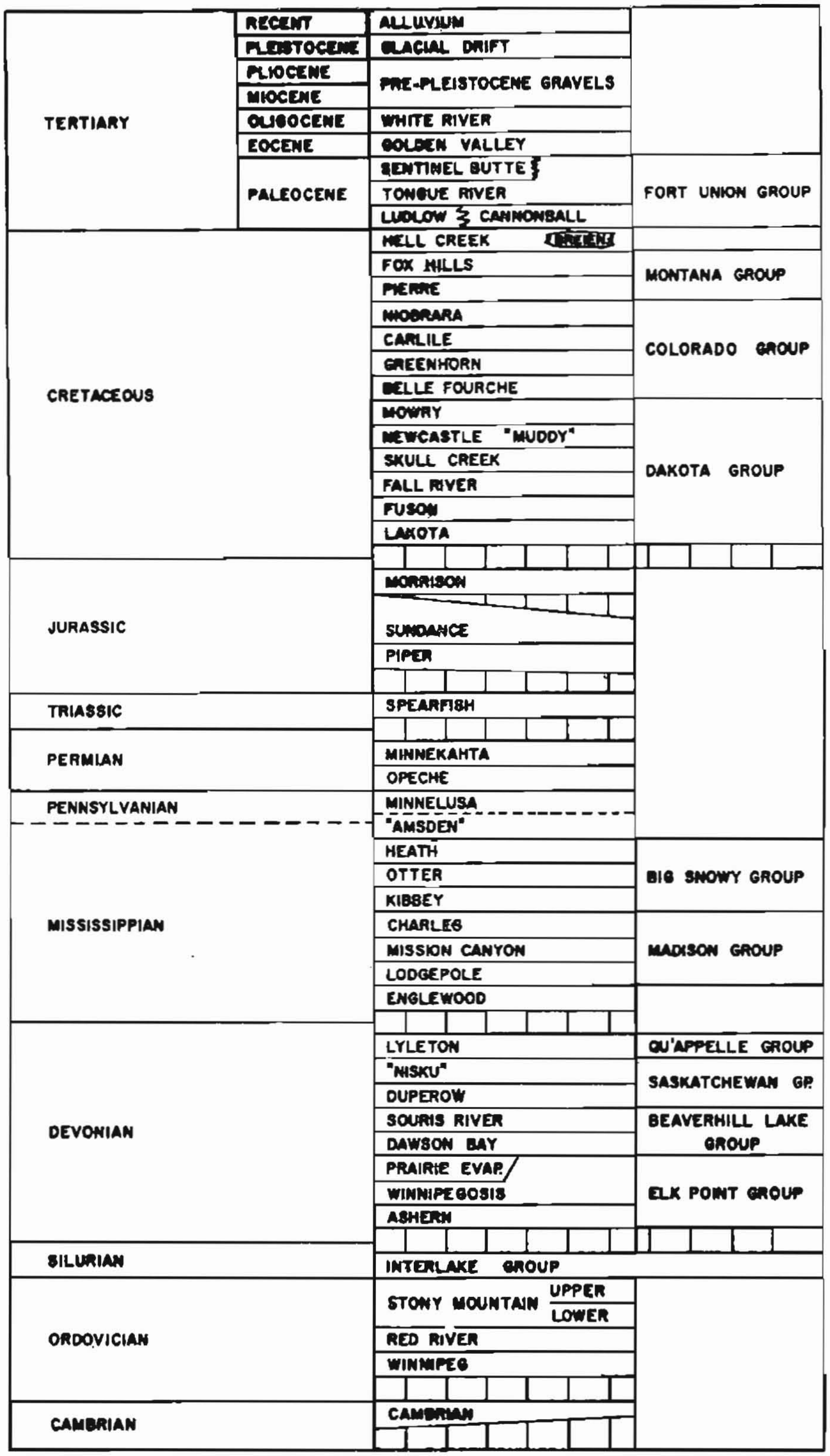

FIGURE 3—Preliminary correlation chart of the Williston Basin.

cross faults, were developed. This is suggested from the rather sharp dips in the pay formation as it passes from field to field particularly between Beaver Lodge and Tioga as well as by the irregular behavior of certain wells as to water production and pressure histories.

Therefore it is felt that the Nesson anticline is due to vertical uplift probably due to a faulting in the basement rock. This uplift has been intermittent over much of geologic time causing not only structural but also sedimentological irregularities adjacent to the site of this particular fold.

It is impossible in the space allotted to give a detailed stratigraphic statement of all the formations found in this particular area. In general, attention will be paid more to the Madison group of formations than any other since these are the oil producing rocks in fields under discussion. (See Figure 3.)

The rocks below the Madison group of formations are not too well known in this area because relatively few wells have penetrated them. However, it is known that rocks of Ordovician, Silurian, and Devonian age are found on the Nesson anticline. Beds representing the Cambrian may also be present. The Silurian and Devonian are both known to be productive in the Beaver Lodge pool and also possibly the Tioga pool. Rocks of Ordovician age have had some shows of oil in the Tioga pool, but it is not known if they are commercial.

The Ordovician through the Silurian is rather largely a carbonate sequence with the exception of some clastic sequences at the base and the top of the Ordovician. The most prominent clastic zone in the section above the Devonian is the Englewood formation of Mississippian age where shales and some small amounts of sandstone are found. Evaporitic sections are known in the rocks of all three of these geologic ages, but the thickest section of the evaporites below the Charles formation of the Madison group occurs in the Devonian. Apparently, this portion of the basin became extensively evaporitic in nature toward the end of middle Devonian time. This evaporitic condition recurred more frequently from Devonian time onward culminating in the Charles formation in upper Mississippian time.

Definite unconformities do exist in the whole stratigraphic section indicated here. The unconformity at the base of the Ordovician is well known particularly on the east side of the Williston Basin. Here in most cases, the Ordovician rests unconformably on the Pre-Cambrian granite. There is some thought that rocks of the Cambrian age may be present, but this has not been definitely proved. If such is the case, then the greatest unconformity, of course, exists at the base of the Cambrian.

The sedimentation between Ordovician and Silurian time was almost continuous and no great evidence of a break does exist. However, there is some suggestion of a break in sedimentation between the Ordovician and Silurian in the outcrop areas in Manitoba. However, this is definitely a minor break if it did exist at all.

W. S. McCabe[1] indicates that there is an unconformity on the top of the Silurian. This is very difficult to ascertain in the subsurface. McCabe also places another unconformity at the top of the Devonian at the base of the Englewood. This also is somewhat difficult to see in the subsurface. A greater amount of evidence exists for it than the one between the Silurian and Devonian.

Some discussion of the rocks overlying the Madison group also is pertinent. Remarks, however, will be confined to discussions of the rocks which are of Mississippian age. Immediately overlying the Madison group is the Big Snowy group of formations. The basal member of this is the Kibbey sandstone. Sloss[2] suggests that the sands of the basal part of the Kibbey indicate an unconformity. This is certainly true in the Montana portion of the basin where they are exposed on the flank of the Big Snowy mountains. McCabe[3] has recently reiterated this conclusion. These unconformities are not obvious in the subsurface and so the contact between the Kibbey and the underlying Charles is not always easily drawn. Overlying the Kibbey are the Otter and Heath formations, respectively, which are largely shale formations. They do, however, in some instances, contain small amounts of black and other colored limestones.

Overlying the Big Snowy group is the Amsden formation. The Amsden formation is of controversial age, geologically speaking. Recently, it has been regarded by many as being largely Pennsylvanian in age. However, there is some evidence that suggests that the basal portion is of Mississippian age. The Amsden in North Dakota is for the most part, regarded as being Mississippian. From the south to the north in the Nesson anticline area, there is a very considerable unconformity at the top of the Amsden formation making a marked thinning of this formation northward.

Madison Group. The Madison group of North Dakota consists of the Lodgepole, Mission Canyon, and Charles formations reading from bottom upward. The group as a whole is rather widespread throughout North Dakota, but the distribution of the Charles formation is more limited than the other two. It is largely a carbonate and evaporitic sequence.

The Lodgepole formation is a gray to brownish limestone with a dense to finely crystalline to medium crystalline texture. Sometimes, the texture may be medium fragmental to coarsely fragmental. It may also contain some chert, shaley limestone and some shale. The color of the Lodgepole may vary from white to a pale orange and pink in color. In the Tioga pool, the formation is 1030 feet thick. The Lodgepole is normally the thickest of the three formations of the Madison group and rests with apparent conformity on the Englewood or Bakken formation. The age of the Lodgepole is Kinderhookian. The presence of chert and other argillaceous limestones suggest that the formation may have been deposited in deeper water, but the fragmental part of the limestone suggests shelf-like conditions.

The Mission Canyon formation is generally a light gray to bright gray limestone with some oolitic to fragmental as well as dense to finely crystalline texture. The porosity of the formations is most marked about 200 feet from the top of the formation where it is both intergranular and vuggy. This porosity is the main pay zone of the formation in the Nesson anticline pools.

In the H. O. Bakken well in the Tioga field, the formation is 450 feet thick. A contact with the underlying Lodgepole is conformable and the upper contact of the formation is definitely gradational with the Charles. The top of the Mission Canyon in most cases is drawn at the base of the last large salt of the Charles formation. This, however, is a purely arbitrary boundary in view of the fact that it is the opinion of the writers that the Charles formation is simply a result of the continuation of Mission Canyon conditions of sedimentation and therefore no actual break between the two actually exists.

The Charles formation in the Beaver Lodge and Tioga field consists of pale brown to light gray, shaly, fine fragmental limestone with some brown shale. It is characterized by some dolomite and several rather large anhydrites. The salt section of the Charles disappears to the east rather rapidly, apparently due to facies change. It is also possible that the salt, as such, is not deposited in the other parts of the state and that there is an unconformable relationship with the underlying Mission Canyon. However, facies changes are apparently the most likely explanation. In the Tioga field, the Charles formation is 630 feet thick. The relationship of this formation to the formations above and below has already been discussed.

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[1] McCabe, W. S., Williston Basin Paleozoic Unconformities: Amer. Assn. of Pet. Geologists Bulletin, Vol. 38, Pages 1197-2010, 1954.

[2] Sloss, L. L., Paleozoic sedimentation of Montana area: Amer. Assn. of Pet. Geologists, Bulletin, Vol. 34, Pages 442-553, 1950.

[3] McCabe, W. S., op cit.

Madison Problems Are Unusual

• Average permeabilities from core analyses give a distorted picture.

• Total production interval 200 feet . . . but net productive thickness is but 60-70 feet.

• Pressure declines below bubble-point are found in some fields.

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THE PAY INTERVAL in the Beaver Lodge and Tioga-Madison pools occurs about 200 feet below the base of the last Charles salt. The porosity is indistinguishable to the naked eye except where vugs occur. A 30x lens is required to see the individual pores. Cores of the formation exhibit both horizontal and vertical fractures which are frequently secondarily filled. There is some doubt as to whether the fractures seen in cores are natural or induced in the coring operation. It would seem logical, however, that a thick limestone such as this would exhibit fracturing, particularly where folding or other structural movement has occurred.

The problem of the cross faulting in these fields has been mentioned previously. Evidence for it at best is indirect and it is not implied that the faults if present, have completely disrupted the continuity of the pay horizon but it would account for some of the problems that arise such as local areas of high water production, variations in water level between pools, and occurrence of dry holes where adjacent development would indicate proven locations.

Core analyses on individual wells show porosities ranging from 22.5 to 0.8 percent with averages of the order of 7 percent. Routine laboratory tests for permeability show horizontal permeabilities from 0 to 750 millidarcys with isolated measurements of 5000+. The higher permeabilities appear to coincide with intervals of vugular porosity, or fracturing.

Coring times in the pay generally drop to 10 minutes or less per foot from the normal drilling rate of 20 or more minutes per foot.

The average permeabilities taken from core analysis give a distorted picture of the existing conditions since the majority of the pay interval has horizontal permeability less than 0.01 of a millidarcy. The isolated intervals of high permeability result in averages over the length of the core, ranging from 0.6 millidarcys to 34.8 millidarcys.

In testimony before the North Dakota State Industrial Commission, a consultant from Houston computed permeabilities from 5.7 to 58.4 millidarcys in Beaver Lodge and from 116.1 to 168.9 millidarcys for Tioga, from production data. In view of the fact that actual laboratory tests indicate low permeability, the producing characteristics of the fields would suggest, rather strongly, that drainage in the reservoirs is due to fractures.

Oil saturation varies from 0 to 87.5 percent of pore space and water saturation varies from 0 to 99.5 percent of pore space. The averages of wells cored indicated saturations of the order of 9 percent for oil and 42 percent for water.

The bulk density of the pay is 2.5 with a matrix density of 2.7. Calculations of porosity based on these measurements give results very close to the averages of the laboratory analysis. From this it is concluded that the figure of 7.82 percent can be used for the porosity of the Madison pay interval in calculations of reservoir volume, without inducing serious discrepancies in the results.

In using electric logs for reservoir calculations a formation factor of 23.746 is suggested for fluid having 150 ohms per cubic centimeter and 5000 ppm NaCl or 79.296 for fluid of 4.8 ohms per cc.

Although the total interval in which production may be encountered totals 200 feet, more or less, the net productive thickness for the pools is about 60 to 70 feet.

The proven area for the Beaver Lodge and Tioga-Madison pools is considered to total 41,200 acres with 25,000 of this within the prescribed limits of the Tioga-Madison pool as presently defined. The Beaver Lodge-Madison pool is well outlined by dry holes and the Tioga-Madison pool is well defined except for the eastern boundary where some possibilities for step-out production may exist.

Although the "pay" interval appears to be continuous between Beaver Lodge and Tioga Pools, they are presently divided into separate units on the basis of a dry hole and two marginal producers which have been abandoned. In the same area, there are still a number of producing wells which are considered marginal. Water production from these wells has been noticeably greater than in the developed areas to the north and south.

In this area, there is also a structural difference of 50 feet over the mile and a half which separates production. A similar condition prevails at the southeast extremity of the Beaver Lodge field where 5 producing wells are separated from the main producing area by a dry hole and a structural difference of 40 feet in ¾ of a mile. Faulting has been suggested for these two areas and would account at least partially, for the excessive water production and generally poor quality of the wells nearby.

The possible productive area for the Charlson-Madison pool is estimated

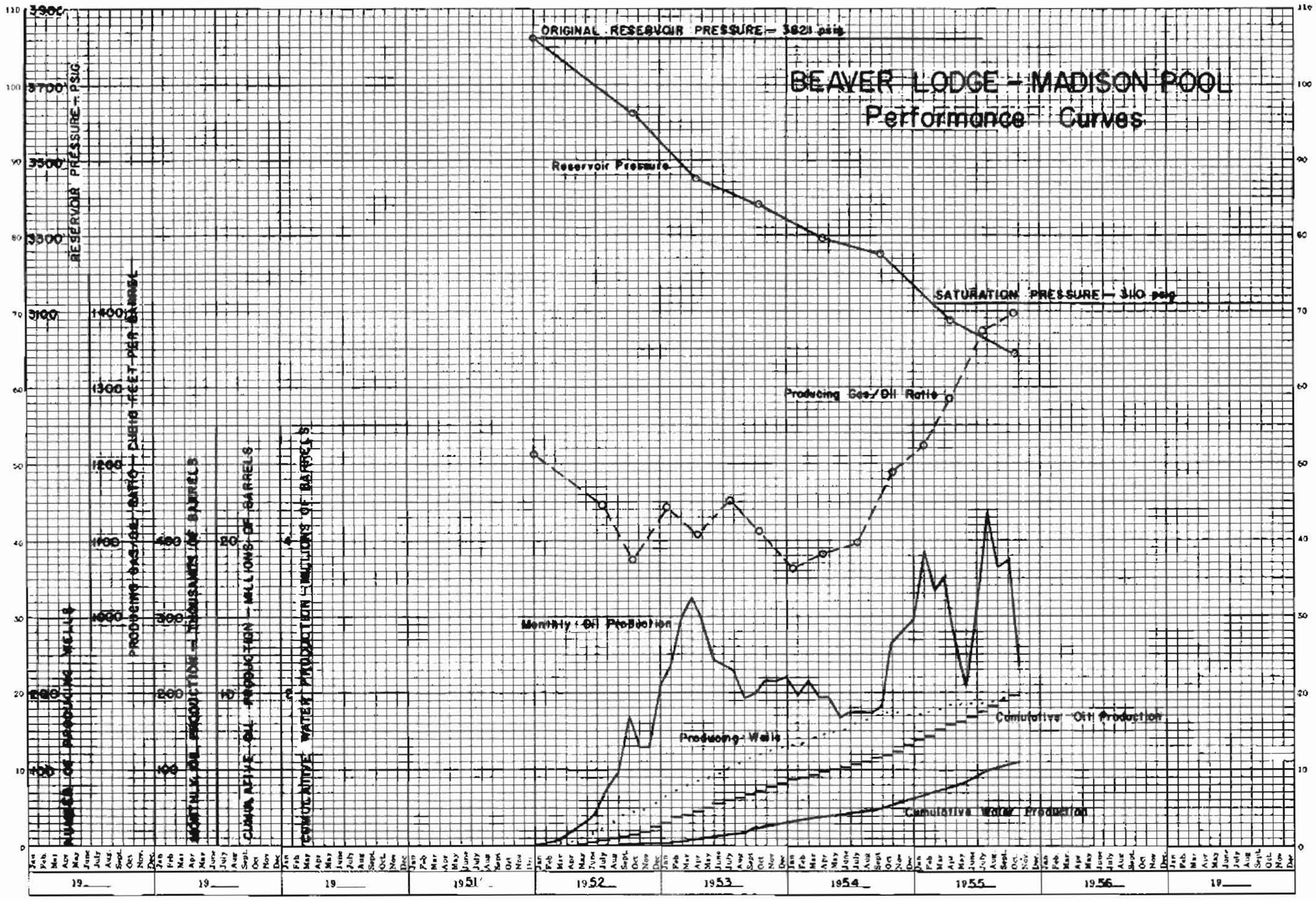

FIGURE 4—Performance curve for Beaver Lodge–Madison Pool.

to be 13,000 acres; for the Capa-Madison pool, 5500; and for the Hofflund-Madison pool 6000 acres. No estimates have been made of the productive area in the Blue Buttes, Croff, and Keene fields due to the lack of development.

In the Charlson-Madison pool, the "pay" interval, as identified by geologists of the North Dakota Geological Survey, reaches a thickness of about 130 feet over the top of the structure. This "pay" interval is an identifiable interval on the mechanical logs and includes both porous and non-porous intervals. From core analysis, the net productive thickness, in the well cored, is probably limited to 35 feet with the total "pay" thinning on the flanks of the structure.

The oil water contact is placed at 6500 feet below the sea level in the Charlson-Madison pool, which results in a maximum oil column of 122 feet for this pool. The water contact is placed at —6260 in the Capa-Madison pool with a maximum oil column of 70 feet; —6155 feet in the Beaver Lodge-Madison pool with a maximum oil column of 138 feet; and —5925 feet in the Tioga-Madison with a maximum oil column of 239 feet. In each case the maximum oil column exceeds the closure.

The oil from the Madison reservoir at Tioga is undersaturated, of low molecular weight, containing 1585 cubic feet of solution gas per barrel of residual oil. The gravity is 44° at 60° F. Reservoir temperature is 212° F. in Tioga and the viscosity was 0.169 centipoises at saturation pressure of 3049 psig. The Beaver Lodge-Madison reservoir had a solution gas-oil ratio of 1773 and viscosity of 0.147 centipoises at saturation pressure of 3205 psig. The gravity of the oil is 43° API at 60° and the reservoir temperature is 224° F. The relative volume factors for the Beaver Lodge and Tioga-Madison reservoirs were 2.135 and 1.983, respectively, at Saturation pressure.

Evaluation data on the produced oil from these fields showed a total sulfur content of 0.34 percent and a Reid vapor pressure of 7.4 pounds. The pour point is 35° F. with 3.5 pounds of salt per 1000 barrels. The Kinematic viscosity was 2.135 centistokes at 100° F. Podbielniak analysis showed 92.4, liquid volume percent, Hexanes or heavier with a specific gravity of 0.8309 and a viscosity, at 100° F. of 2.641 centistokes.

The characteristics of the reservoir fluid from the other Madison pools on the anticline are similar. Solution gas-oil ratios are 1598, 1651, and 1952 in Charlson, Hofflund, and Capa fields, respectively.

It is interesting to note the increase in the API gravity of the oil which occurs up dip to the north. Readings for the fields, beginning with the furthest south, are Croff- -41.9, Blue Buttes—40.7, Keene—41.5, Charlson —41.6, Hofflund—42.8, Capa—43.4, Beaver Lodge—43.0, and Tioga—44.

Reservoir temperatures are Croff—231°, Blue Buttes—238°, Charlson—224°, Hofflund—228°, and Capa 226° F. The viscosity of the oil is 0.132 cps. at Capa. Relative volume factors are 2.064 for Charlson, 2.083 for Hofflund, and 2.261 for the Capa field, at saturation pressure of 3211 psi, 3085 psi, and 3302 psi respectively.

The reported GOR for the Clarence Iverson well in the Madison pool

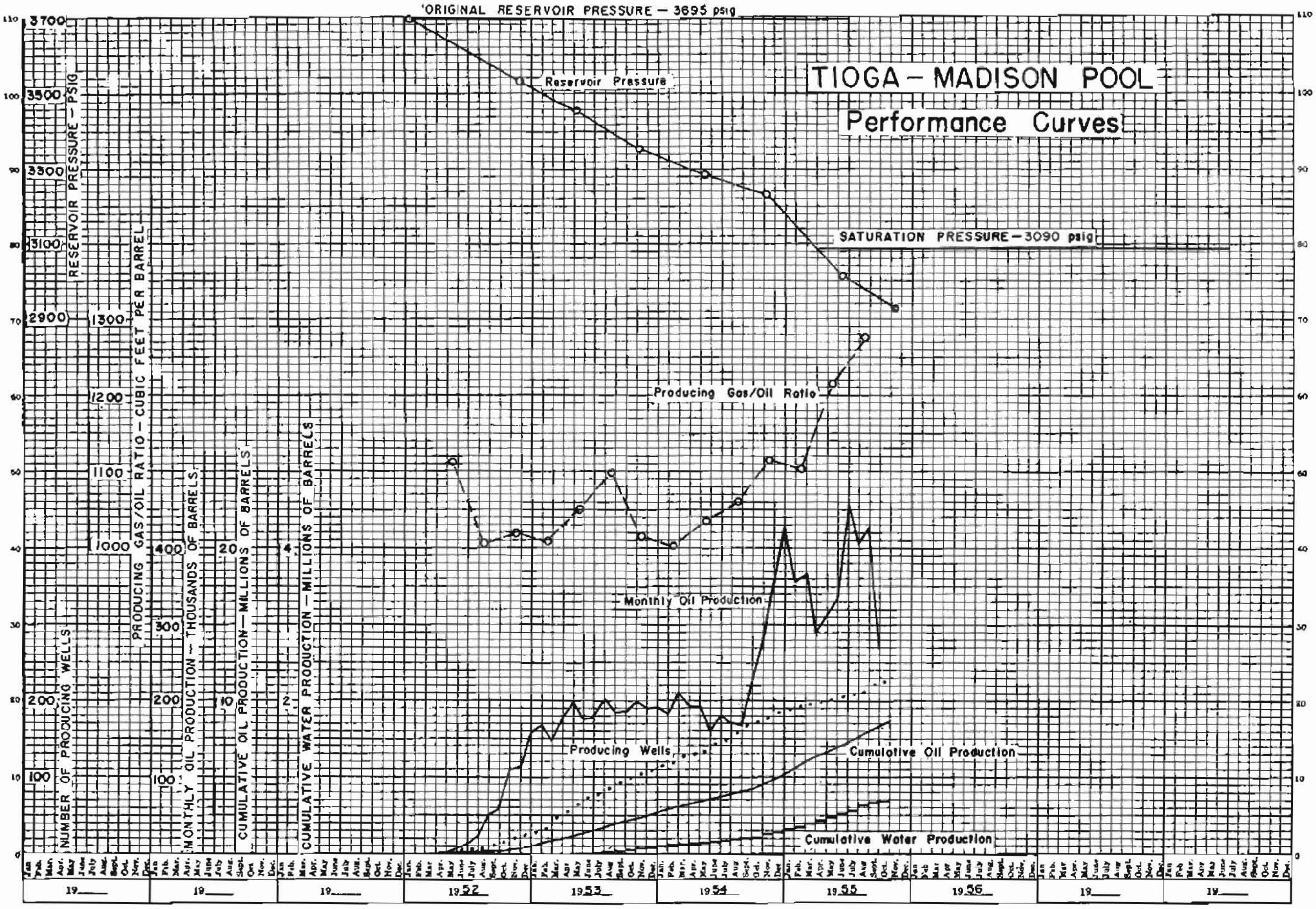

FIGURE 5—Performance curve for the Tioga–Madison Pool.

in Beaver Lodge was 1211 cubic feet per barrel, initially. The average gas-oil ratio for the field was varied, reaching a low of 1062 in the first quarter of 1954. Since that time, it has increased steadily to its present average value of 1374 cubic per barrel. (See Figure 4).

In the Tioga field, the initial GOR for the discovery well was 1094 cubic feet per barrel. The lowest ratio, 1001 cubic feet per barrel was reached during early 1954 and the present average value of 1273 cubic feet per barrel represents a steady rise. (See Figure 5).

Both pools have now declined in pressure below bubble point. Saturation pressure was passed during the first half of 1955 for both fields. Present average bottom-hole pressures are 3079 psig and 3015 psig for the Beaver Lodge and Tioga pools, representing declines of 616 and 646 psi, respectively.

The pressures in the two pools have declined similarly. The decline had been following a uniform curve until January, 1955. Since that time, both decline curves have broken sharply, still moving parallel, and have dropped below saturation pressure. This break coincides with the increase in production, from 355,000 barrels per month to 800,000 barrels per month, that occurred when the market demand increased at the end of 1954.

Some consideration has been given to the possibility that this interrelation between production rate and pressure reaction indicates the approximate MER in each case. On this basis it would appear that production should be stabilized at about the rate prevailing during 1953. However, a different idea is suggested when actual declines are compared to the theoretical curves for the fields.

Simple mathematical equations which would represent the natural relationship between reservoir pressure and time are as follows:

- Beaver Lodge-Madison pool
  $\text{Log } P = 3.58218 - 0.00240\ t$
- Tioga-Madison pool
  $\text{Log } P = 3.56761 - 0.00226\ t$

Where P is reservoir pressure in psig and theis time in months.

It can be seen that the two curves are very similar. The pressures used are corrected to the datums for each pool:—6100 for Beaver Lodge and —5850 for Tioga. If the pressures for the Beaver Lodge curve are corrected to the Tioga datum, there remains a difference of about 50 psi between the curves.

This would indicate that the two pools are not connected, although their performance is similar, and that the drainage mechanism is the same for both pools. This, together with the GOR behavior, would suggest the presence of depletion-type drainage.

When the actual pressure decline is plotted against the mathematically determined curve, it can be seen that both pools have followed the theoretical curve closely. In the case of the Tioga-Madison pool, the actual decline is still above the theoretical curve and the actual curve for the Beaver Lodge-Madison pool has been coincident for practical purposes. On the basis of these curves, it appears that the MER for the two pools is about equal to the current withdrawals at this writing.

At the beginning of the second quarter of 1955, the average of the productivity indices of individual

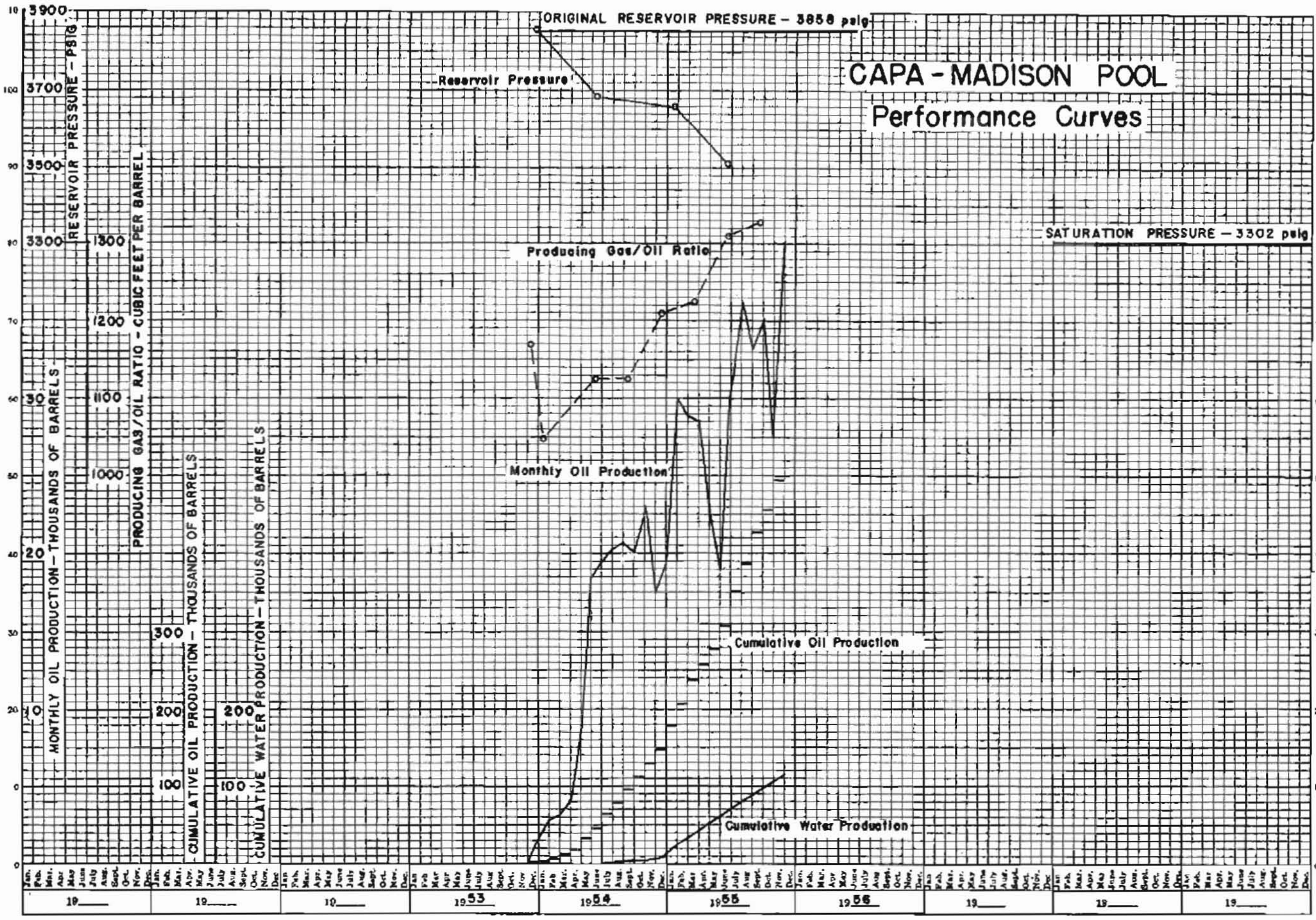

FIGURE 6—Performance curve for the Capa–Madison Pool.

wells in the Beaver Lodge and Tioga-Madison pools were 122.27 barrels of oil/psi, pressure drop, and 90.95 barrels of oil/psi respectively. The distribution of the indices is shown in Table 1.

TABLE 1
Productivity Index—Bbls/psi
Number of Wells in Each Group

PI	Beaver Lodge	Tioga
0– 50	14	13
50–100	51	105
100–150	71	26
150–200	18	7
200	4	4
Total	158	155

From the table it can be seen that Tioga appears to be the more uniform of the two pools. Whereas more than ⅔ of the wells checked in the Tioga-Madison pool had indices between 50 and 100, only ⅓ of the wells in the Beaver Lodge-Madison pool fell within this range with an additional 45 percent having indices between 100 and 150 barrels of oil per psi. The ranges of productivity index encountered were from 15 to 536 barrels of oil per psi for Beaver Lodge-Madison and from 16 to 388 barrels of oil per psi for the Tioga-Madison pool.

The original gas-oil ratios for the other Madison pools were: Croff 1501 cubic feet per barrel, Blue Buttes 1020 cubic feet per barrel, Keene 1296 cubic feet per barrel, Charlson 949 cubic feet per barrel, Hofflund 1570 cubic feet per barrel, and Capa 1167 cubic feet per barrel. (See Figures 6, 7, and 8). Although some variations have occurred between successive measurements, the present gas-oil ratios are between 1150 and 1350 cubic feet per barrel, in these fields.

Estimated recoverable reserves of crude oil for the Beaver Lodge and Tioga-Madison pools are 95 and 150 million barrels, respectively, as of October 1, 1955.

Total recoverable wet gas, available, for sale, after processing at the Signal Oil & Gas Company's Tioga plant is estimated to be 265 billion cubic feet from the two reservoirs. The deliverability of these reserves is important and it should be recognized that the amount of gas available on any day will be dependent upon the market demand for crude oil and the MER of these pools since the production of oil will be regulated by these two factors.

In a conflict of interest between the consumers of the natural gas and the responsibility of the state to prevent waste of oil, the state will exercise its police power to regulate the oil production.

In attempting to compare these estimates of reserves with earlier, similar, estimates, it should be remembered that the boundaries of the two pools were changed by the State Industrial Commission in its orders of October 29, 1955.

Reserves have been estimated for the Charlson, Hofflund, and Capa-Madison pools at 45 million, 20 million, and 35 million barrels respectively.

Operators seeking to establish production in the fields of the Nesson anticline are faced with a number of unusual problems not ordinarily encountered elsewhere. Since the Madison limestone reservoir lies directly beneath the Charles formation, all wells must penetrate 200 to 400 feet of crystalline salt section. The early

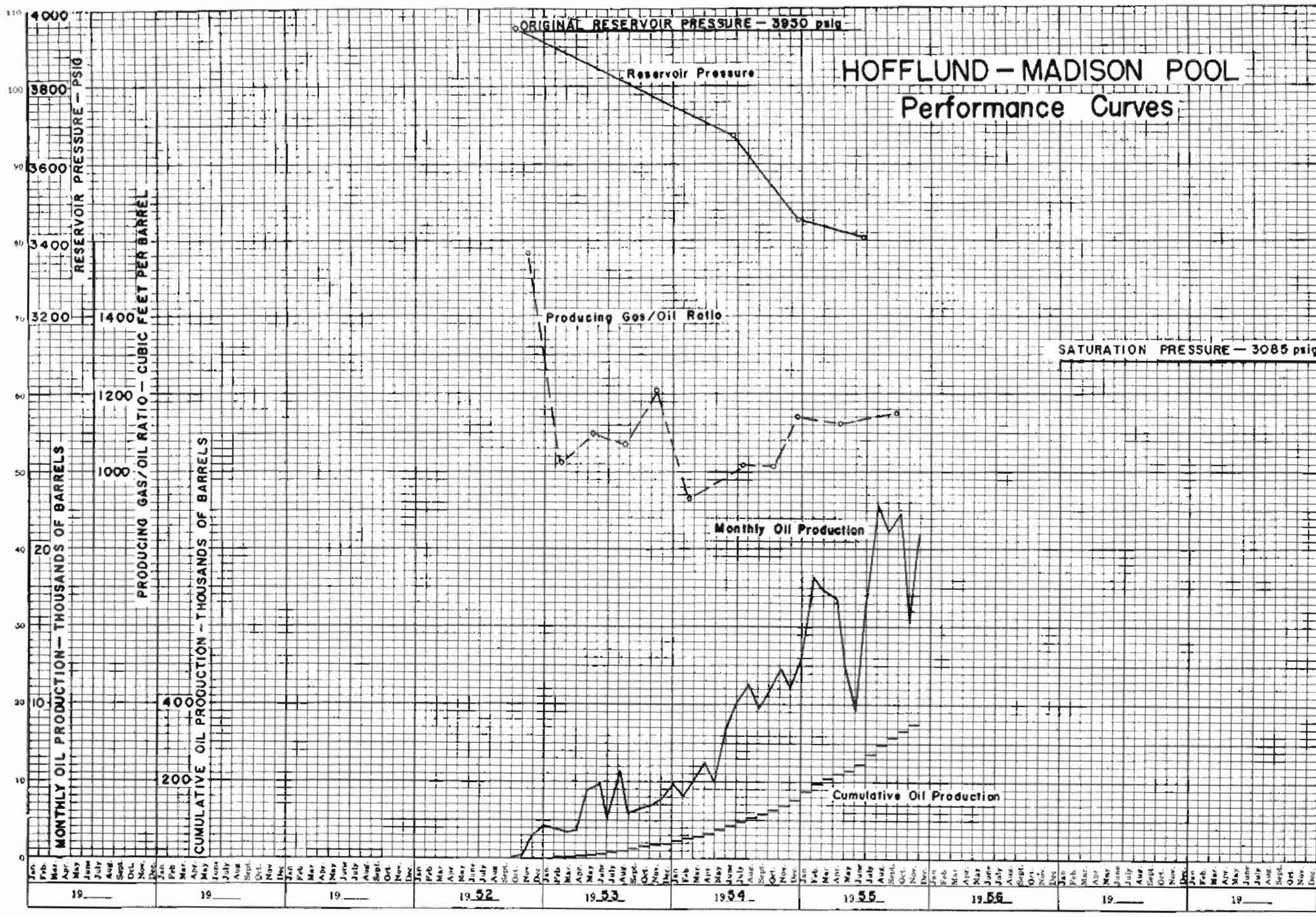

FIGURE 7—Performance curve for the Hofflund–Madison Pool.

drilling programs called for a production string of 5½-inch OD casing, made up of 15.5 and 17 pound seamless casing.

Casing was set at 10,823 feet in the Palmer Dilland well in April, 1952. In June, 1954, it was necessary to kill the well, and move in a workover rig due to loss of production. It was found that the casing had collapsed opposite the salt section and had partially flattened the tubing. Similar circumstances were found in other wells throughout the fields. Although the exact reason for this failure has not been clearly established, it is thought that plastic deformation and subsequent movement of the salt is responsible.

In an attempt to eliminate this trouble, salt base mud is now used when drilling this section. The use of this type mud should result in holes of uniform gage. Recent wells have been cased with 7-inch OD 23 pound-32 pound-35 pound N-80 casing as a further precautionary measure.

Due to the increased use of salt base mud, most of the salt water from production was utilized and its disposal was not a problem. With development nearly completed, thought is being given to the establishment of a down-hole disposal system. One of the larger operators has already laid a system of concrete pipe for the gathering and transportation of this water to disposal wells. It will be injected into the Lakota formation of Cretaceous age through dry holes and previously abandoned producers on the edges of the fields.

The weather constitutes another difficulty of considerable proportions. The heavy snowfall and the drifting which occurs require a great deal of maintenance work on roads, lease equipment, and vehicles. Since the pour point is only a little above the normal winter temperatures, difficulty is experienced in the maintenance of piping and valves.

Drilling operations are continued through the winter at a somewhat reduced rate. Rigs are winterized and steam generating equipment is used for heating the rig and thawing lines, pits, etc. Some hazards exist, due to the weather, which would not ordinarily be encountered. One of these is the possibility of fire when taking drill stem tests, due to the enclosure of the rig floor, such as occurred on a Penrod rig in Tioga field during the winter of 1954-55.

It is estimated that the annual cost of maintaining production in these fields is about $10,000 per well; most of it as a result of the rigorous climate.

North Dakota is now faced with a rather unusual problem for an inland state, namely offshore drilling. The completion of the Garrison reservoir will result in the flooding of much, possibly productive land. Three methods of developing the flooded area were considered. These were drilling barges, earthen mounds, and directional drilling. The use of drilling platforms or barges was discarded because of expense and the danger of severe damage from ice.

One well already completed in the flood-plain was raised on an earthen mound to bring the wellhead above the high water level. The mound is approximately 41 feet high with a 600-foot causeway to the shoreline. The mound measures 60 x 80 feet at the water line and the roadway is 30

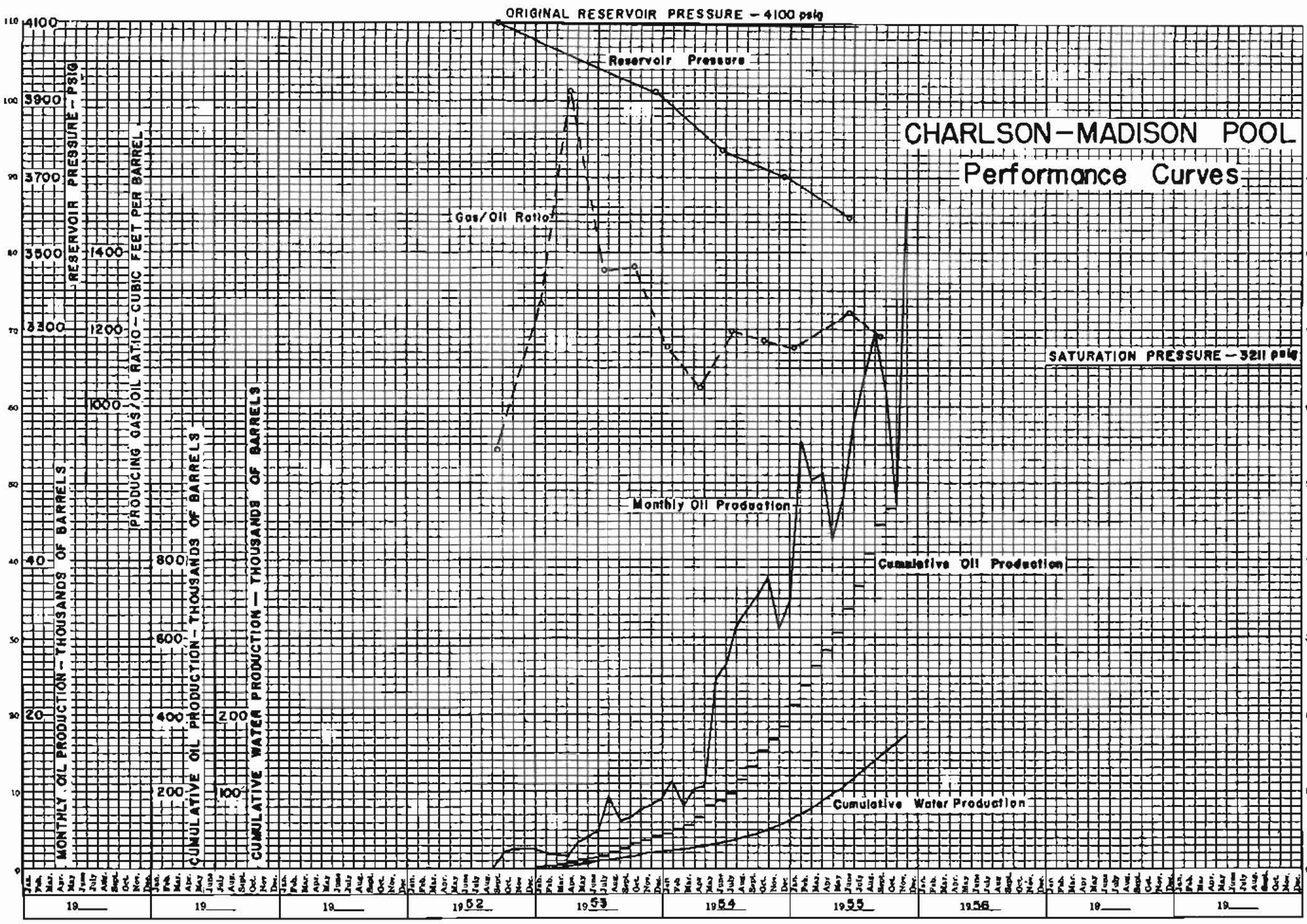

FIGURE 8—Performance Curve for the Charlson–Madison Pool.

feet wide. Side slopes are 2 to 1, covered with a 12-inch gravel filter and 18 inches of riprap. The top of the structure is finished with 3 inches of gravel and native 'scoria.' In the causeway fill is buried a 4-inch, welded, gathering line. The cost of the structure was approximately $65,000.

Directional drilling was deemed to be the most satisfactory method of reaching the underwater area and on 24 June 1954, Amerada Petroleum Corporation spudded its J. G. Viall Tract 1 No. 1 on the north bank of the reservoir. The well was deviated 1893 feet to the southeast and was completed in 63 days at a cost of about $215,000. The drilling proceeded without incident and the well was completed in the prescribed location. Although directional drilling is not a new technique in the oil industry, this was the first attempt to carry out such an operation in an area of well indurated rocks.

On July 7, 1955, a second directional well was spudded on the south bluff. It soon became apparent that the directional surveys were not accurate and the well was plugged back from 7768 to 3555 feet where drilling was resumed. It is thought that the difficulty arose from the use of a single, 18 foot, K-monel drilling collar. After plugging back, two collars, totaling about 30 feet, were run and the source of the difficulty appears to have been eliminated.

To date, the directional drilling has been limited to locations within 2000 feet of the drilling site. In this distance drift angles are kept at less than 25°. To reach more distant locations, much lower angles would be necessary.

Paraffin in the production becomes a serious problem when withdrawal rates are curtailed. In order to reduce maintenance costs, the operators are allowed to produce their monthly allowable in as little as 5 days. The rule limits production rates to 600 percent of the daily allowable, but the total allowable for any month shall not be exceeded.

Proration to market demand is in effect by virtue of a statute enacted by the 1953 legislature. The market demand is allocated among the pools, and the wells in the pools, so as to distribute the market on an equitable basis. A proration unit is a 40-acre tract of land and a normal unit allowable is set each month for a proration unit. This normal unit allowable is then adjusted for depth and gas-oil ratio in setting the final daily allowable. When more than one proration unit is incorporated in a drilling unit the allowable for the well on that drilling unit is increased proportionately.

In setting spacing patterns for the development of these fields, the Industrial Commission has followed the principle of setting wide spacing for initial development, in order to establish more quickly the limits of the pool and obtain data on the reservoir. A final proper spacing is determined when sufficient data has accumulated to form a basis for a sound determination.

By tying the proration to tracts of land rather than wells, and thus increasing the allowable for wide spacing, the effect of spacing changes on the income of land owners and royalty

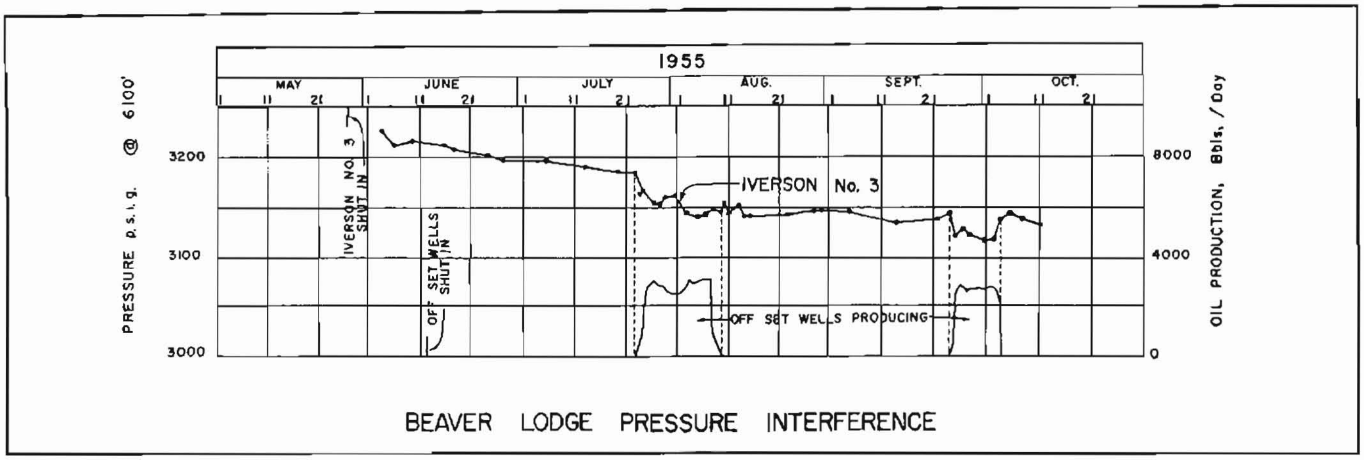

FIGURE 9—Results of interference test in Beaver Lodge–Madison Pool. Note how form of the production curve is reflected in the pressure curve.

owners is nil. Under such conditions, the decision on spacing can be based on technical evidence.

In the hearings held this year to determine the proper spacing for the Beaver Lodge-Madison, Tioga-Madison, Hofflund-Madison, and Charlson-Madison pools, evidence was offered to show that the pay interval, in these pools, is reasonably uniform; that there is communication between wells in the pools; and that wells, in these pools, are draining areas as great as 1000 acres.

Four principle forms of evidence have been introduced:

- Electric logs have been used to trace the pay interval from well to well and demonstrate its uniform character.
- Graphs have been introduced to show that wells drilled in recent months have recorded initial reservoir pressures close to the prevailing pressure, for that portion of the field, as shown by regular measurements in adjacent, earlier wells.
- Mathematical calculations have been made on the basis of production data to show the pressure distribution at various distances from wells. The calculation involves a modified form of the Darcy Law equation and the resulting pressures are plotted against drainage radius. From these graphs, it can be shown that wells draining an area of low permeability cause greater pressure drops, and therefore fluid movement toward them, than wells completed in areas of greater permeability. The slope of the pressure distribution curve at any point indicates the direction, and rate, of fluid flux at that point.
- During the summer of 1955, the Amerada Petroleum Corporation conducted extensive tests in the Beaver Lodge-Madison and Tioga-Madison pools. For the purpose of these tests, nine selected wells were shut in on the first of June and pressures were observed until mid-October. During the last week of July, offset wells to four of these test wells, two in each pool, were placed on production and two months allowable was taken over a two week period. These offset wells were shut in about 40 days prior to the production test. The drop in pressure, at the observation well, was recorded, and charted, and the resultant graphs showed clearly the communication between the test wells and their offsetting wells, drilled on the 80-acre pattern. The test was repeated again during the last week of September and the first week of October and the same results noted. (See Figure 9).

The remaining five observation wells, two in Tioga and three in Beaver Lodge remained shut-in during the entire four-month test period. The pressures recorded on these wells indicated a regular decline although the wells were not producing, showing that the reservoir was reacting to withdrawals from wells as much as 1980 feet away. The witness at the October hearing of the State Industrial Commission who introduced the results of the tests stated that the oil saturation of the reservoir was being reduced a the rate of one-fourth of 1 percent per 100 psi.

The market for crude oil produced from the Nesson anticline is, at this time, limited to the amount that can be processed by the Standard Oil Company of Indiana refinery at Mandan, N. D., and the Westland Oil Company refinery at Williston and the amount used by the operators in drilling and lease operations. For December, 1955, this market totaled 36,300 barrels per day and this approximates the MER for present fields. (A small amount of this crude goes to the Queen City refinery).

The oil is purchased by Stanolind Oil Purchasing Company at a posted field price of $2.90 per barrel. The oil is transported from Tioga to Mandan by Service Pipe Line Company through its crude oil line. Service Pipe Line Company also maintains the gathering lines in the fields.

A small refinery was built at Williston in 1954 but was later sold to the Westland Oil Company. Operation was resumed in November, 1955. The rated capacity of the refinery was 1500 barrels per day.

Signal Oil & Gas Company completed its Tioga gasoline plant in October, 1954. This is a very modern plant and was designed particularly for the climatic conditions in the area. No water cooling was used and the cooling system is equipped with heaters for winter use. All water used in the plant is confined to enclosed areas.

In addition to the usual products, this plant produces over 20 tons of elemental sulfur per day. The operation of this plant has practically eliminated the flaring of gas in the fields.

Residue gas equalling about 65 percent of the wet gas intake will be taken by Montana-Dakota Utilities for their Tioga-Minot pipe line. This line is also connected to their other distribution system at Williston in order that excess gas from the Tioga plant, during the off-peak season may be sent to underground storage in eastern Montana. —The End