NORTH DAKOTA GEOLOGICAL SURVEY

Wilson M. Laird, State Geologist

Report of Investigation Number 32

Preliminary Report on the *Antelope - Madison* and *Antelope - Sanish* *Pools*

by

Clarence B. Folsom, Jr.

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Grand Forks, North Dakota, 1959

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GEOLOGY OF THE ANTELOPE FIELD

CLARENCE G. CARLSON AND SIDNEY B. ANDERSON

INTRODUCTION

This report discusses in a preliminary way the geology and engineering characteristics of the Antelope Sanish and Antelope Madison pools. Because the pools are located on the same structure they have been included in the same report.

The part of the stratigraphic column from the Qu'Appelle formation of Devonian age through the Charles formation of Mississippian age is discussed in some detail. The overlying strata which consist of nearly 8200 feet of sedimentary rocks in some of the wells range in age from Tertiary to Mississippian and are not discussed.

The writers wish to thank the other members of the geological and engineering staff of the North Dakota Geological Survey for helpful suggestions, criticisms and for drafting the illustrations.

STRATIGRAPHY

Devonian

The term Lyleton shale was introduced by Allen and Kerr (1950, p. 10) "to designate red dolomitic shales and siltstones that overlie predominantly carbonate strata at the top of the Devonian section and underlie the bituminous black shale in the (Souris Valley Oil Co.) Robert Moore No. 1 well near the village of Lyleton in southwestern Manitoba." A check of this well shows that they were not referring to this well but rather were referring to the Souris Valley-Gordon White No. 1 well. This is clearly an inadequate description for the naming of a new subsurface unit according to Report 4 of the American Commission on Stratigraphic Nomenclature (1956, p. 2013).

Baillie (1953,p.2013) proposed the term Qu'Appelle group to include all the silty argillaceous and anhydritic strata that overlie the Nisku formation of the Saskatchewan group and underlie the dark gray to black bituminous shale that marks the base of the Mississippian in the Williston basin area. Baillie used the term Lyleton formation in southwestern Manitoba and eastern North Dakota as equivalent to the Qu'Appelle group but in the deeper parts of the Williston basin he did not subdivide the Qu'Appelle group. Although there are lithologic similarities between the Qu'Appelle group of the Williston basin and the Three Forks formation of southwestern Montana, their correlation as exact equivalents has not been demonstrated. Therefore, we prefer a term which has been defined within the Williston Basin and herein accept the term Qu'Appelle as defined by Baillie. However, since we cannot further subdivide the Qu'Appelle group we have changed its rank

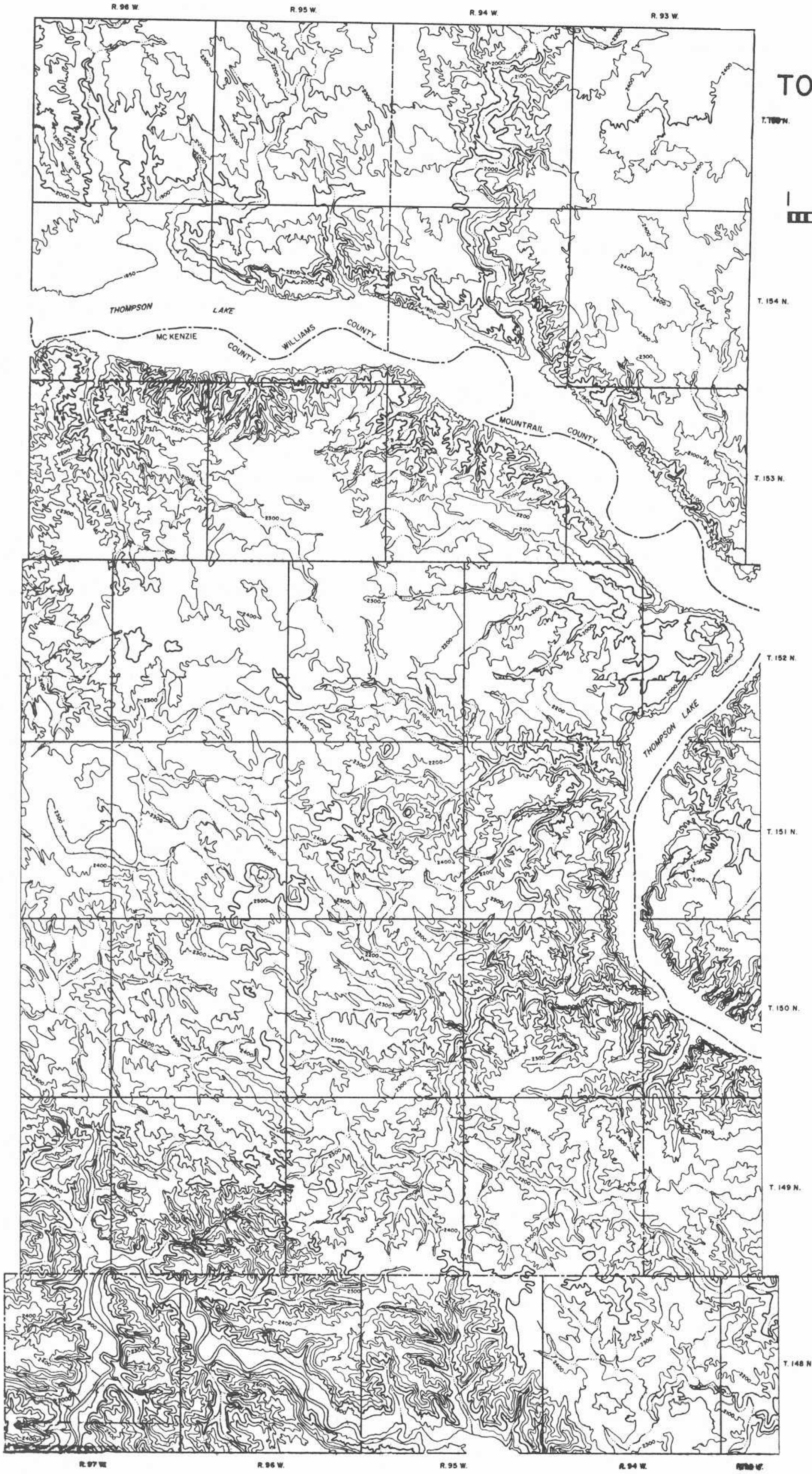


FIGURE NO. 1
TOPOGRAPHIC MAP
OF AREA

C.I. = 100'

1 0 1 2 3 4 5

SCALE IN MILES

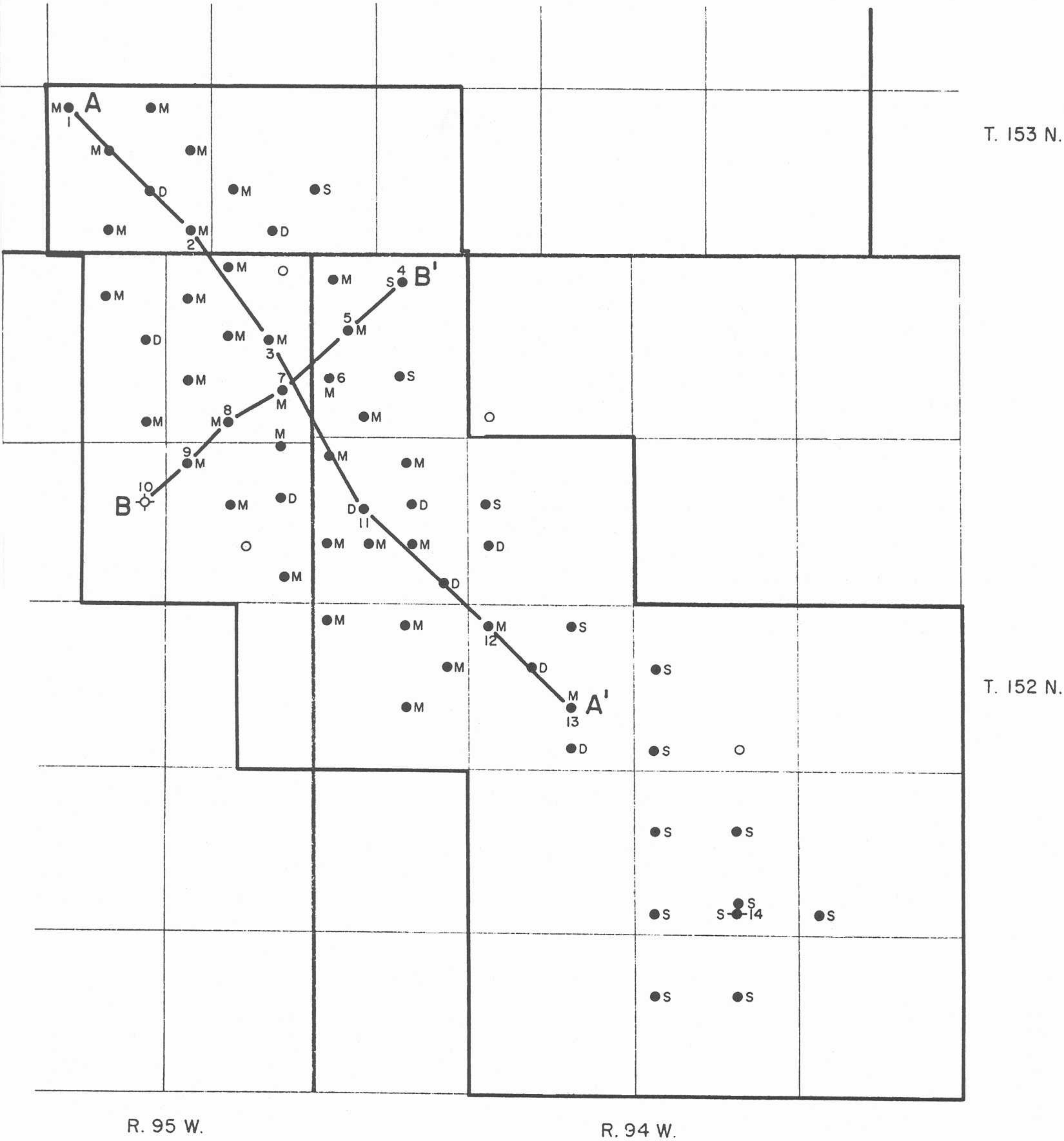


FIGURE NO. 2 - MAP OF ANTELOPE FIELD

M = MADISON WELL
S = SANISH WELL
D = DUAL COMPLETION

to formational status.

In the Antelope field area the Qu'Appelle formation of Devonian age has a total thickness of 195 feet in the Pan American Petroleum Corporation - W. Starr No. 1 well located in the SW, SW, Sec. 21, T. 152 N., R. 94 W., McKenzie County, North Dakota. The lower part of the Qu'Appelle formation consists of grayish-red and greenish-gray, silty, dolomitc shale grading upward into a brownish gray, silty dolomite with minor amounts of anhydrite near the base. The upper part of the Qu'Appelle formation consists of brownish gray, dolomitic siltstone, cross-bedded in part, interlaminated and interbedded with greenish gray, pyritic shale. In this area a sandstone unit, informally termed the "Sanish" sandstone by the North Dakota Geological Society (1954, p. 56) is present at the top of the Qu'Appelle formation. This unit consists of up to seven feet of brownish gray, fine to very fine-grained angular, quartzose sandstone, which is overlain by the Bakken formation. There is some question whether this sandstone unit should be placed in the Qu'Appelle formation or the Bakken formation.

The overall lithologic aspect of the Qu'Appelle formation is one of transition from finer clastics at the base to slightly coarser clastics in the upper part. In contrast the basal deposits of the overlying Bakken formation are black shales representing euxinic conditions. Therefore the "Sanish" sandstone appears to be more closely related to the lithology of the Qu'Appelle formation than that of the Bakken formation, so it is herein included in the Qu'Appelle formation.

MISSISSIPPIAN

Madison Group

The Madison group unconformably (?) overlies the Qu'Appelle formation. In the Antelope field area the Madison group ranges in thickness from 2,191 to 2,293 feet, thinning slightly over the crest of the fold as well as thinning generally toward the northwest. The Madison group comprises four formations which are in ascending order: Bakken formation, Lodgepole formation, Mission Canyon formation, and Charles formation.

Bakken formation

The term Bakken formation was introduced by the Williston Basin Nomenclature Committee at a meeting in Bismarck, in February, 1953 for a shale, siltstone and limestone unit at the base of the Mississippian section in the Williston Basin. It was used without formal definition on regional cross-sections published by the North Dakota Geological Society (1953) and in their publication, Stratigraphy of the Williston Basin (1954).

The Bakken formation was formally named and described by Nordquist (1953, p. 72). The type section is in the Amerada Petroleum Corporation -

H. O. Bakken No. 1 well, located in the SW, NW, of Sec. 12, T. 157 N., R. 95 W., Williams County, North Dakota where it occurs between the depths of 9615 and 9720 feet. His description of the type section is as follows.

	Thickness	Depth
Shale, black, fissile, very slightly calcareous	20	9615-35
Sandstone, light gray to gray brown, very fine-grained calcareous interbedded with minor amounts of gray-brown cryptocrystalline limestone.	60	9635-95
Shale, black, fissile, very slightly calcareous	25	9695-9720

Previously the term Bakken formation has not been used in publications of the North Dakota Geological Survey. However, current studies of the lower unit of the Mississippian section and the upper part of the Devonian section indicate that the Bakken formation is a well defined and useful stratigraphic unit. Therefore we have accepted the term Bakken formation for this report.

The relationship of the Bakken formation to the Englewood formation is a regional problem and will not be discussed in this report. Our preliminary thought is that the Englewood formation is higher stratigraphically than the Bakken formation and is probably equivalent to the shale which is present in the lower part of the Lodgepole formation south of the Nesson Anticline.

The Bakken formation in the Antelope field is very similar to the section in the type well. The lower unit is composed of 13 to 32 feet of brownish black to black shale, the middle unit is composed of 37 to 45 feet of brownish gray, silty limestone and calcareous siltstone and the upper unit is composed of 22 feet of black shale.

Lodgepole formation

The Lodgepole formation is the lower limestone unit of the Madison group, which was first described by A. C. Peale (1893, p. 33). A. J. Collier and S. H. Cathcart (1922, p. 173) named the formation for exposures in Lodgepole Canyon in the Little Rocky Mountains of eastern Montana, where, according to Collier and Cathcart, the Lodgepole consists of fossiliferous thin-bedded limestone and shales, having a thickness of 800 feet. Sloss and Hamblin (1942, p. 313) state that the type section of the Madison group is near the town of Logan, on the Gallatin River, Gallatin County, Montana. Holland (1952, p. 1703) agrees with Sloss and Hamblin in this and states that the Lodgepole formation has a thickness of 584 feet at the type section.

The Lodgepole formation conformably overlies the Bakken formation. The contact between the Lodgepole and Mission Canyon formations as well as the contact between the Mission Canyon and Charles formations are quite arbitrary in the deeper parts of the Williston Basin. Detailed correlations of these formations from their type areas to the deeper parts of the Williston Basin are rather tenuous at best. Thus some of the operators along the Nesson

Anticline have preferred to use a "Madison limestone" top, picked at the base of the last salt, rather than the formational terminology. Such usage includes within the "Madison limestone" all of the Lodgepole and Mission Canyon formations and the lower part of the Charles formation.

The Lodgepole formation consists of about 750 feet of light gray to medium gray, dense, fragmental, limestone, cherty and shaly in part.

Mission Canyon formation

The Mission Canyon is the upper unit of the Madison limestone as it was first described by A. C. Peale (1893, p. 33). The formation was named by Collier and Cathcart (1922, p. 173) for exposures of 500 feet of massive white marine limestone in Mission Canyon in the Little Rocky Mountains.

The Mission Canyon formation consists of about 500 feet of brownish gray to light gray, fragmental, fossiliferous limestone, dolomitic in part and containing very minor amounts of anhydrite in the upper portion.

Anderson (1958, fig. 9) recently described the facies relationship of the Charles and Mission Canyon formations. The upper part of the Madison group, which is composed mainly of evaporites was termed the "Charles magnafacies" and the underlying predominantly carbonate sequence was termed the "Mission Canyon magnafacies." That is, eastward from the center of the basin Charles type evaporites cross time lines and extend into the Mission Canyon and conversely westward from the edge of the basin the Mission Canyon type limestones extend upward into the Charles. Following this nomenclature the top of the "Mission Canyon magnafacies" would be 231 feet below the base of the last salt, at the base of the last anhydrite in the Amerada Petroleum Corporation - T. Lacey No. 1 well located in the NW, SW, Sec. 6 - T. 152 N. - R. 94 W. (See fig. 3) in the Antelope field.

Charles formation

The Charles formation was first named by O. A. Seager (1942, p. 864) from the Arro Oil and California Company's Charles No. 4 well, SE, NW, Sec. 21, T. 15 N, R. 30 E., Garfield County, Montana, where he described it as a sequence of limestone, anhydrite, brown and red shales and siltstones, and dolomite lying between the Kibbey and Mission Canyon limestones. Seager placed the Charles formation in the Big Snowy group, but he did not designate the interval.

Sloss, (1952-p. 65) however, placed the Charles at the top of the Madison Group. Later Nordquist (1953, p. 79) placed the interval between the Kibbey limestone and the Mission Canyon limestone, being from 3196 to 3800 feet in the type well.

The lower part of the Charles formation, which is included in the

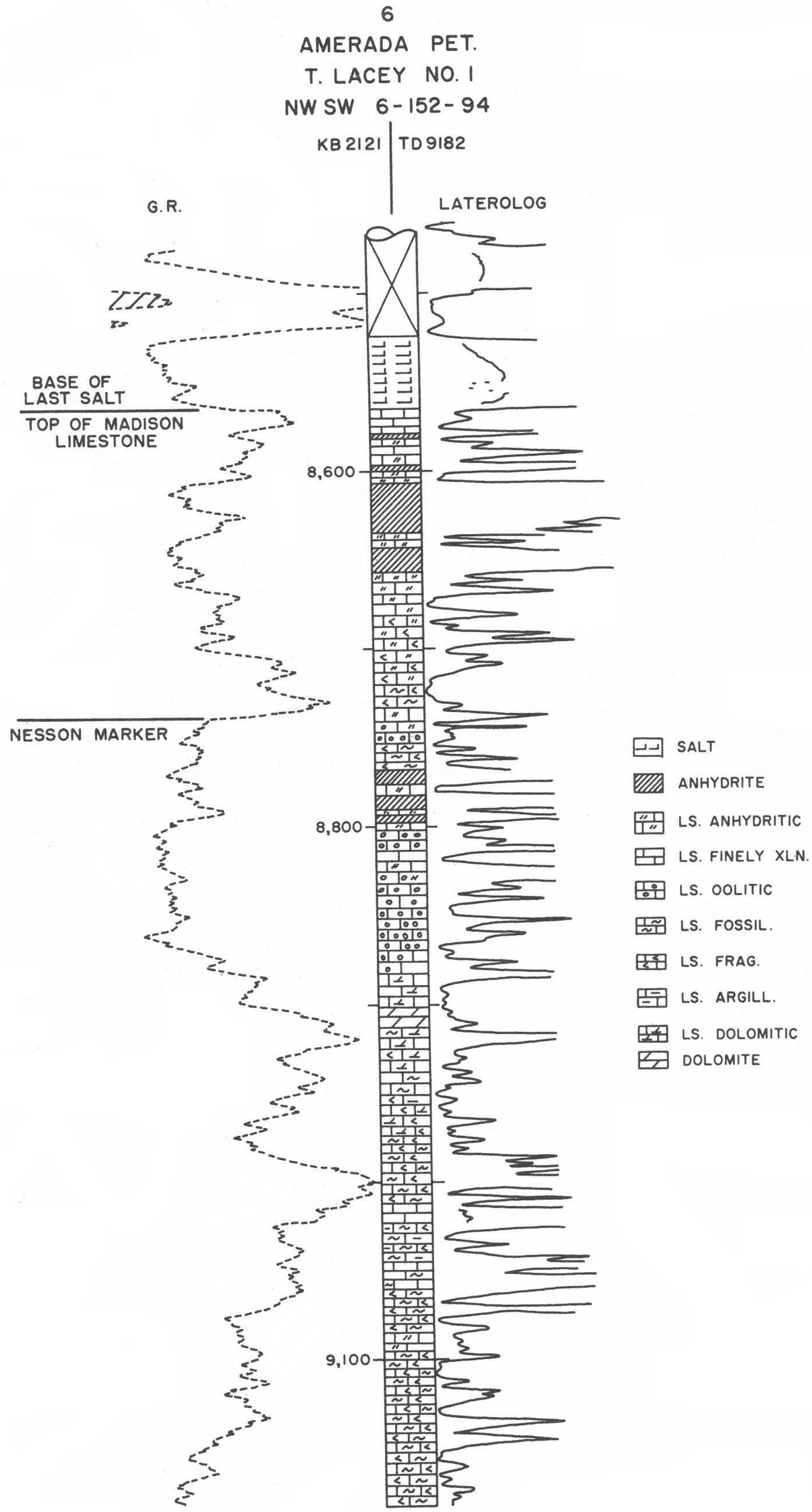


FIGURE NO. 3 - LITHOLOGIC AND MECHANICAL LOG CHARACTERISTICS OF THE UPPER PART OF THE MADISON LIMESTONE

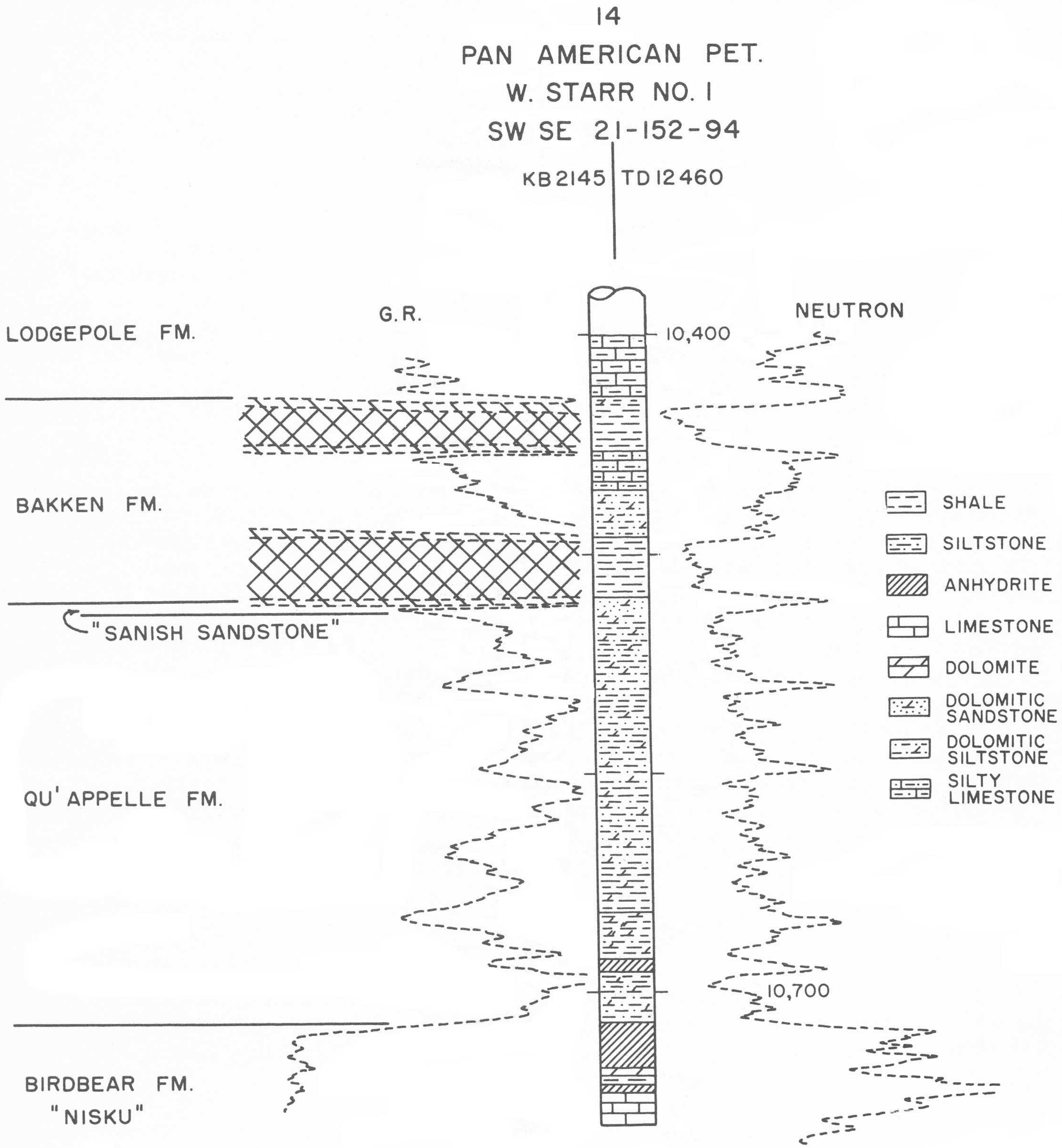


FIGURE NO. 4 - LITHOLOGIC AND MECHANICAL LOG CHARACTERISTICS OF THE BAKKEN FORMATION AND THE QU'APPELLE FORMATION

"Madison limestone," consists of about 325 feet of light brownish gray to brownish gray, fossiliferous limestone, fragmental in part and oolitic to pisolitic in part, interbedded with white to light gray anhydrite. The upper part of the Charles formation is about 675 feet thick, of which about 340 feet is salt. The salt is interbedded with limestone, light brownish gray, finely crystalline; anhydrite, light gray and shale, light gray, medium gray and pale reddish brown.

Cores of the upper part of the "Madison limestone" have been cut in two wells in the Antelope field, namely, the Amerada Petroleum Corporation - T. L. Lacey No. 1 located in the NW, SW, Sec. 6, T. 152 N., R. 94 W, and the Amerada Petroleum Corporation - Brenna, Norby Unit No. 1 located in Lot 5, Sec. 1, T. 152 N., R. 95 W. A portion of the log of the Amerada Petroleum Corporation - T. L. Lacey No. 1 was chosen to show a typical gamma ray-laterolog together with more detailed lithologic information of the upper part of the "Madison limestone" (fig. 3).

Cores of the lower unit of the Bakken formation and/or the upper part of the Qu'Appelle formation are avilable from eleven wells in the field. These cores have staining in the dolomitic siltstone and silty dolomite of the upper part of the Qu'Appelle formation as well as in the "Sanish" sandstone. The wells are usually completed in both the sandstone and the upper siltstone beds of the Qu'Appelle formation. A portion of the log of the Pan American-W. Starr No. 1 well was chosen to show the lithology and a typical gamma ray-neutron log of the Bakken and Qu'Appelle formations, (fig. 4).

Two cross sections (figs. 5 & 6) were constructed to show the part of the Madison group which is productive in the Antelope field. The datum used is sea level to show the structure of the Madison reservoir. Several intervals of this formation have been tested and found productive. These intervals or zones have received informal names, but this type of stratigraphic usage has been discouraged. For production purposes, the Madison group is treated as one reservoir.

STRUCTURE

The structure of the Antelope field has previously been interpreted to be either an asymmetric anticline or a faulted anticline. In the present study, the writers prepared four structure maps for the purpose of evaluating these hypotheses. The four maps prepared are:

1. A structure map on the base of the Bakken formation (fig. 7).

2. A structure map on the top of the "Nesson Marker," without a faulted structure (fig. 8).

3. A structure map on the top of the "Nesson Marker," with a faulted structure (fig. 9).

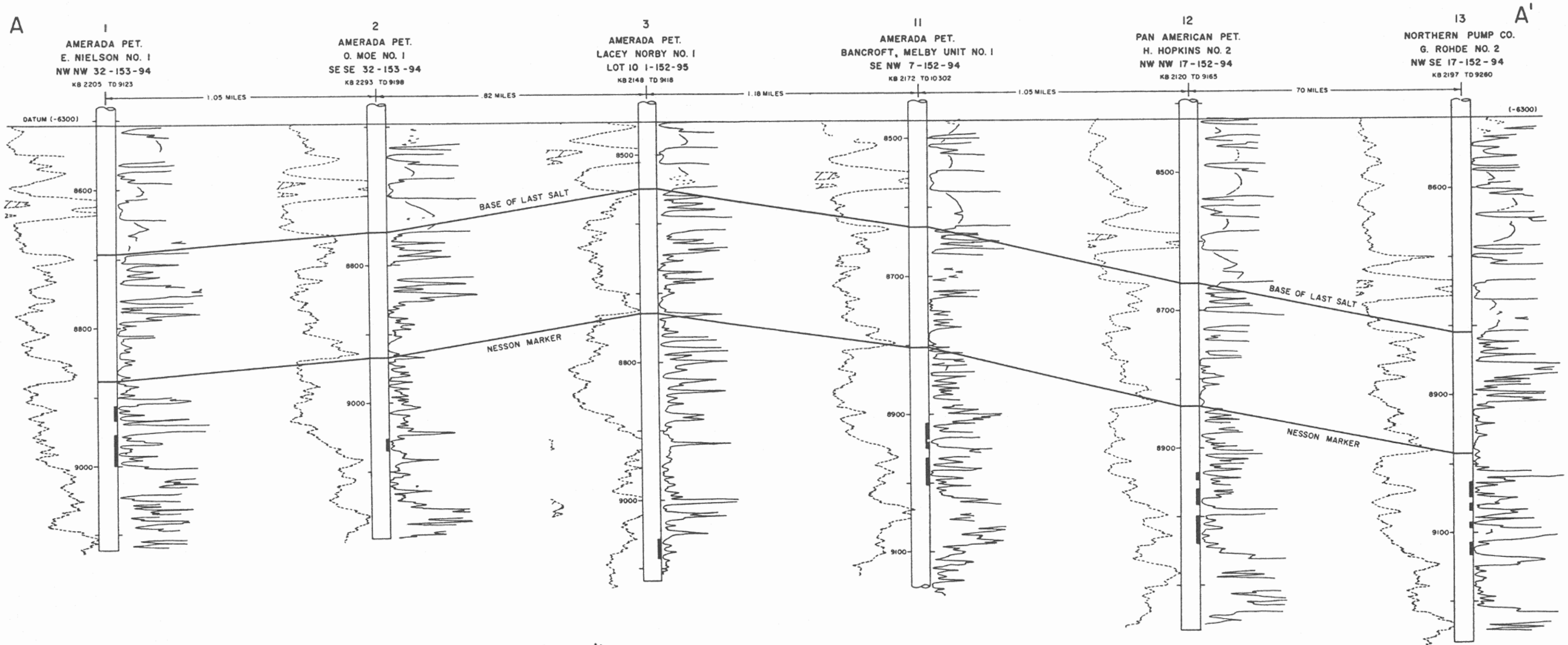


FIGURE NO. 5 - CROSS-SECTION (A-A')
ANTELOPE FIELD NW-SE

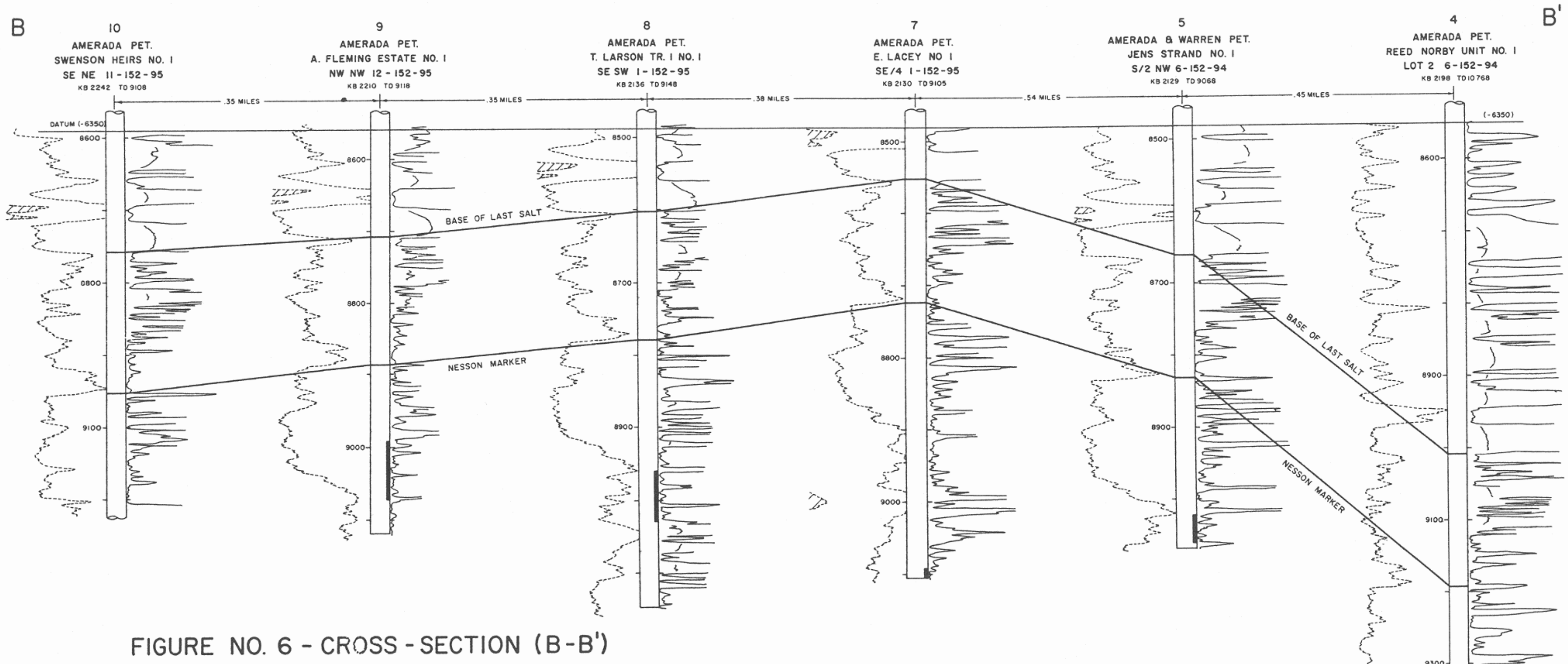


FIGURE NO. 6 - CROSS-SECTION (B-B')
ANTELOPE FIELD NE-SW

4. A structure map on the top of the Greenhorn formation (fig. 10).

A study of these structure maps indicate that the Antelope field is an asymmetric anticlinetrending North 40° West, with either a steeper dipping limb or a fault on the northeast flank of the structure. In either case the closure of the fold increases with depth, at least down to the Madison, the closure being 10± feet on the Greenhorn formation and 80 feet on the "Nesson Marker." The maximum closure of the "Sanish" reservoir cannot be determined because the structure has not been completely drilled out to the northwest, however, it is assumed that the closure is greater than in the Madison reservoir.

One explanation of the Antelope structure is that the structure is a reflection of topographic relief of the Precambrian basement and that differential sedimentation and/or compaction of sediments has accounted for the lesser amount of closure in the younger beds.

An alternate explanation is that the steeper dip on the northeast flank of the fold is due to faulting in the Precambrian basement. The steeper dip is in the same area on all three horizons. Therefore, if a fault is present, its surface must be very highly inclined and must have been active intermittently with a gradually lessening effect through geologic time from the Bakken formation to the Greenhorn formation.

OIL ACCUMULATION

Sanish Reservoir

In the Sanish reservoir the best wells in terms of actual daily production are found on the northeast flank of the fold or along the trace of the proposed fault although good wells are found on both sides of the proposed fault. The gas/oil ratios and the bottom hole pressures are also similar on both sides of the fault. This suggests that it is a continuous reservoir hydrodynamically, and that the production is controlled by two factors: 1) structure and 2) quality of the reservoir rock (i.e. thickness of the sandstone and its permeability).

An examination of cores and core chips on file with the North Dakota Geological Survey and of core descriptions where the chips were not available show that a sandstone unit, four to five feet thick, previously referred to as the "Sanish" sandstone, is present on the east flank of the fold and in the southeastern part of the field. Cores of the only two wells in the Antelope field which are dry in the "Sanish" reservoir did not contain any sandstone at the top of the Qu'Appelle formation.

The writers examined the core of the Pan-American Petroleum Corp. - George Lewis No. 3 well, located in the SE, NE, Sec. 18, T. 152 N., R. 94 W. In this well the top of the cored interval (10, 365 to 10,390 feet) is at the top of the Qu'Appelle formation of Devonian age according to the

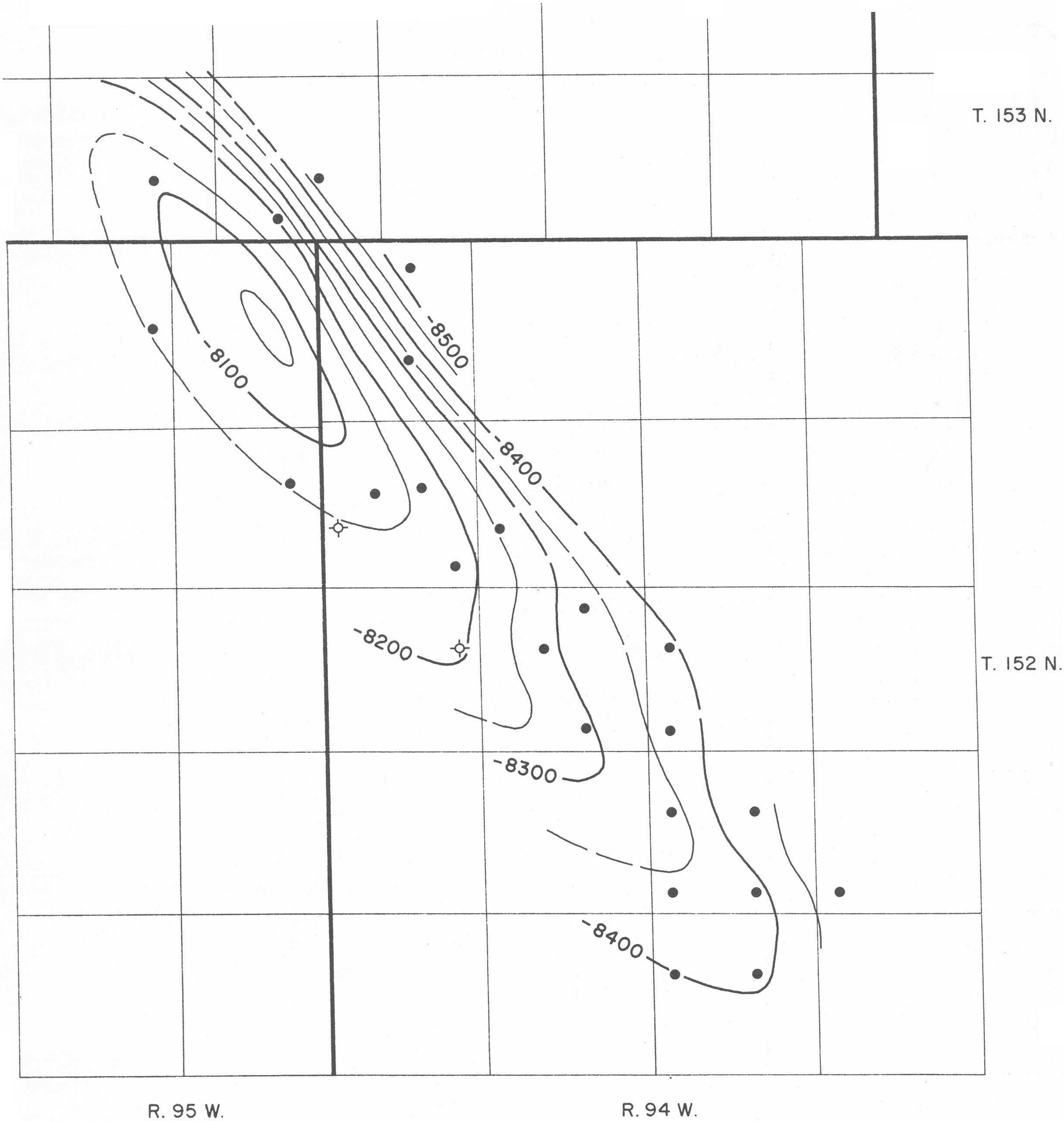


FIGURE NO. 7 - STRUCTURE ON BASE OF BAKKEN FORMATION

C.I. = 50'

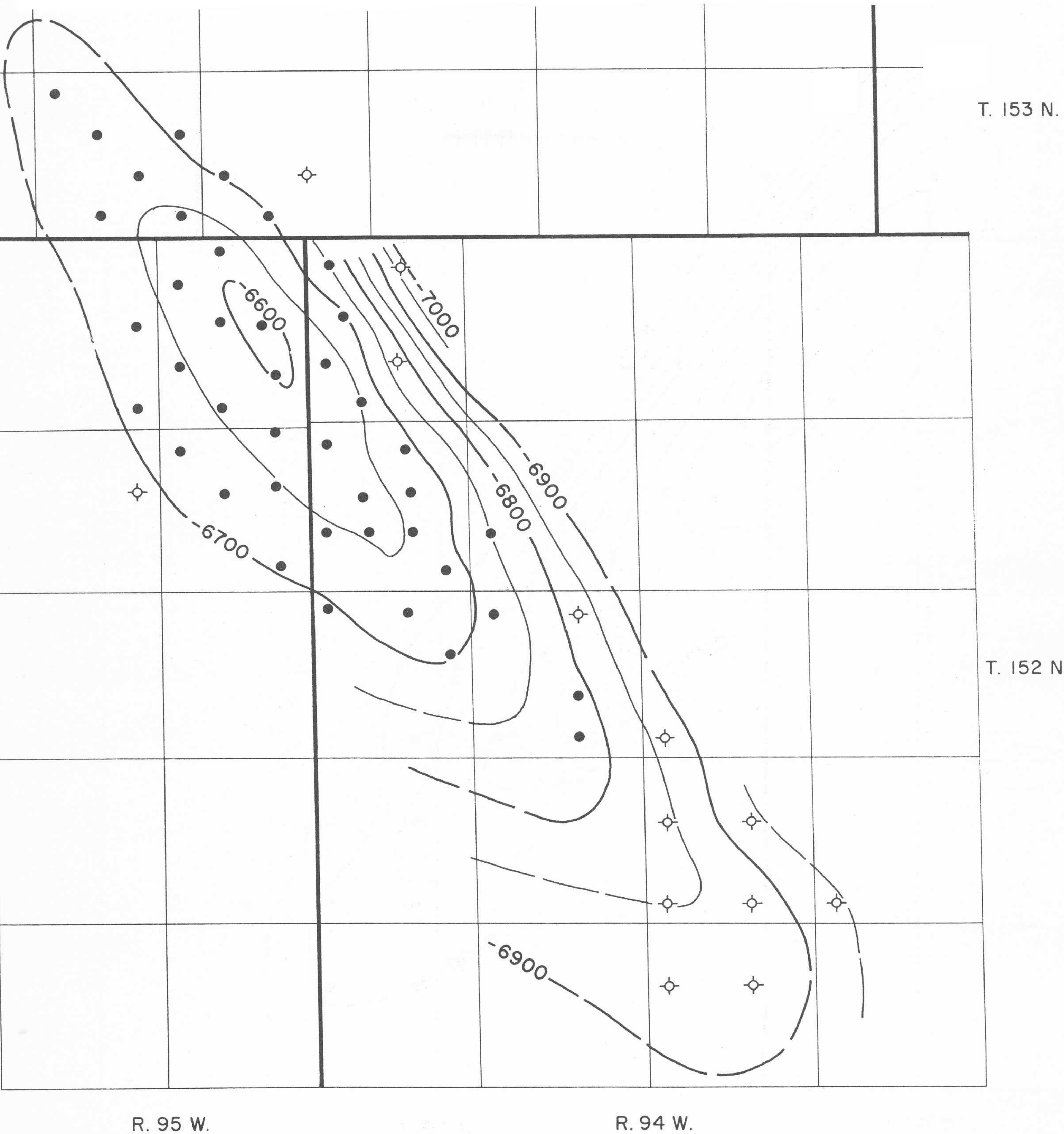


FIGURE NO. 8 - STRUCTURE ON TOP OF "NESSON MARKER"

C. I. = 50'

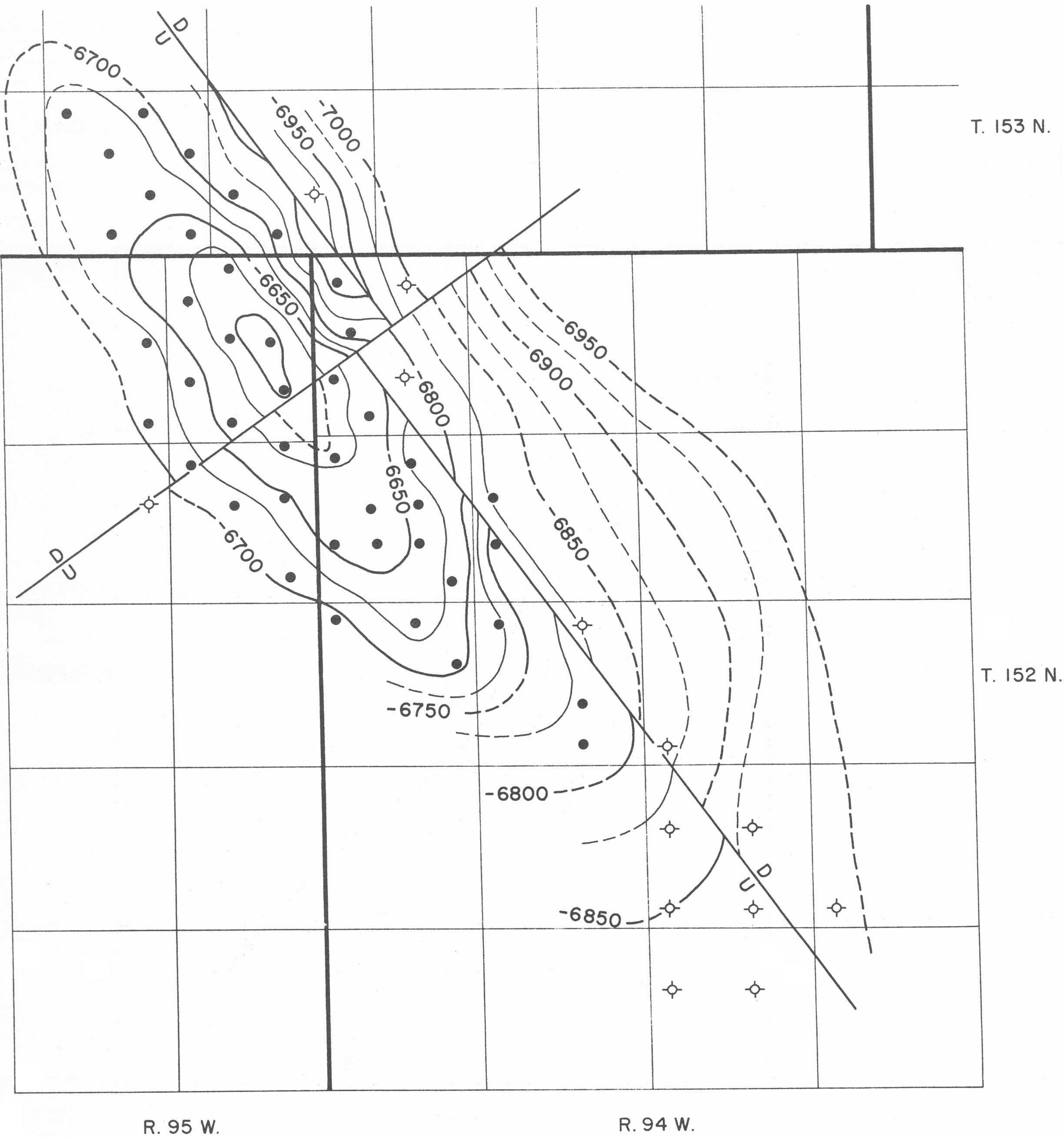


FIGURE NO. 9 - STRUCTURE ON TOP OF "NESSON MARKER" (FAULTING INFERRED)

C. I. = 50'

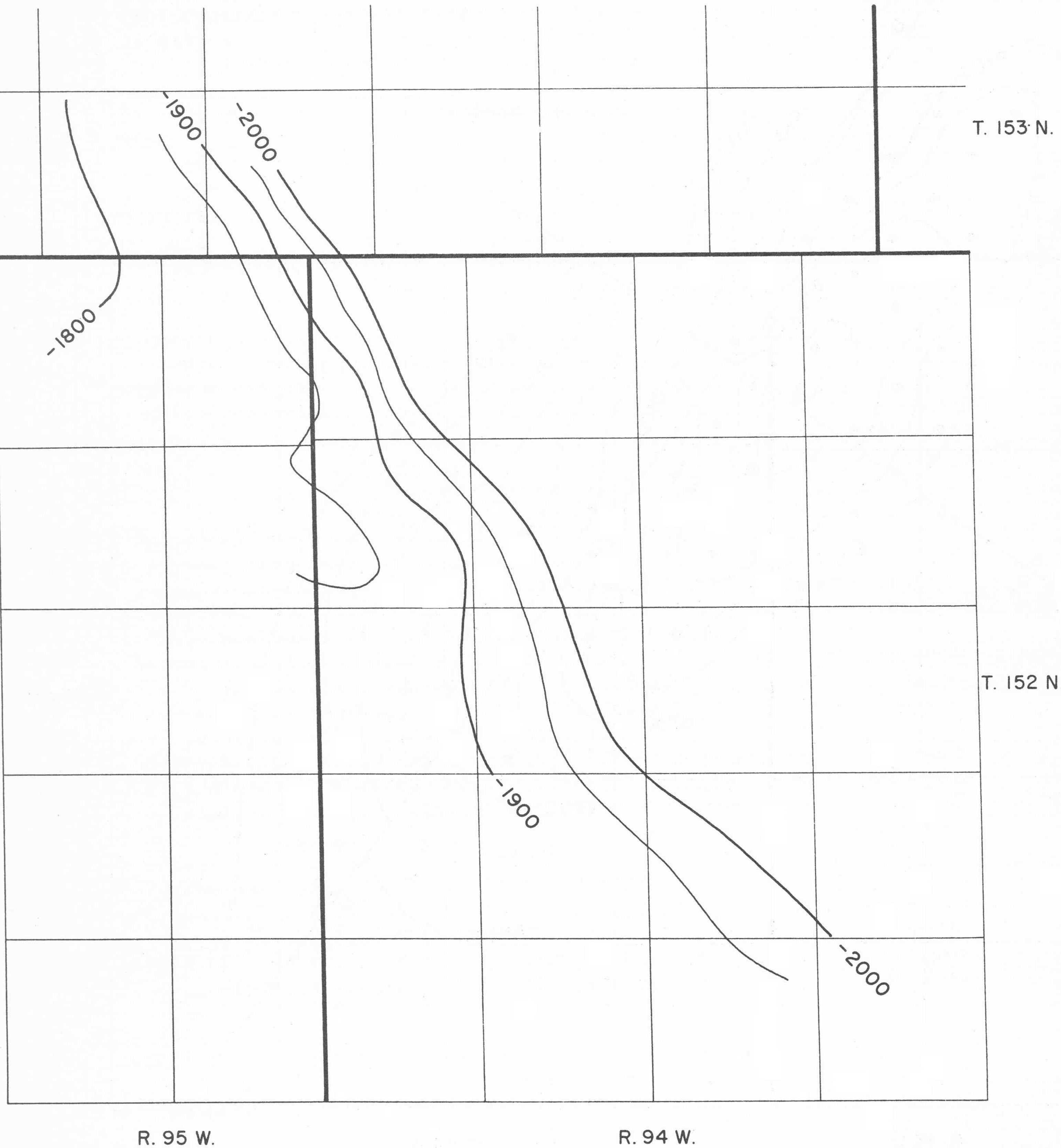


FIGURE NO. 10 - STRUCTURE ON TOP OF GREENHORN FORMATION

C. I. = 50'

radioactivity log, however, no shale of the lower unit of the Bakken formation (Mississippian) was included in the cored interval so the absence of the sandstone mentioned above cannot be definitely established.

Core descriptions made by the Pan American Petroleum Corp. in their H. G. Price No. 3 well, located in Lot 7, Sec. 7, T. 152 N., R. 94 W., describe the cored interval, (10,354 to 10,372 feet) which includes the Bakken - Qu'Appelle formational contact, as composed of "three feet of black shale overlying 55 feet of interbedded and interlaminated silty dolomite and green shale, hard and tight." An attempt was made to complete this well in the "Sanish" reservoir, but after producing 62 barrels of oil it was plugged back and produced from the Madison reservoir.

Two other wells on the southwest flank of the fold in the northwest part of the field are marginal producers from the "Sanish" reservoir. This suggests that the structure may have been effective in limiting the deposition of the "Sanish" sandstone to the northeastern, eastern and southern flanks of the fold.

Madison Reservoir

The limits of the Madison reservoir in the Antelope field have been fairly well defined by dry holes on all sides of the structure except toward the northwest, and there, the northwesternmost well is a pumping well.

The Madison reservoir is similar in lithology to the Madison reservoirs in the other fields along the Nesson anticline. It is composed of oolitic limestones; fossiliferous, fragmental limestone and dolomitic limestone. (see fig. 3). The oolitic limestone is brownish gray with a finely crystalline matrix, partially recrystallized to a finely crystalline limestone so the primary porosities have been reduced. The light brownish gray, fossiliferous, fragmental limestones have poor to fair porosities. The best porosity is developed in the light brownish gray, microgranular, dolomitic limestones.

The core analysis of the Madison limestone in the Northern Pump Co. - G. T. Rohde No. 1 well, located in the SW, SE, Section 17, T. 152 N., R. 94 W, is the only one available in the Antelope field. In this well the maximum porosity is 19.5%, but generally they are less than 7%. The matrix permeabilities are low, generally less than 0.1 md., but the fracture permeabilities are good.

The producing interval for a representative sample of the wells in the field is shown on the cross-sections (figs. 5 & 6). They show that wells located highest on the structure produce from lower horizons stratigraphically than do the wells on the flanks of the fold.

The gross pay thickness in the Antelope field is greater than in other fields along the Nesson anticline. This is partially explained by the greater closure in the Antelope field. However, the gross pay thickness exceeds the closure of the structure as is also true in other Nesson anticline fields.

FUTURE POSSIBILITIES

In the Antelope field the Madison pool is almost completely developed, however, in the "Sanish" pool there are a number of promising locations on the northeast flank of the fold and as extensions toward the northwest.

Deep tests elsewhere along the Nesson anticline have shown the "Sanish" sandstone to be quite erratic. In the Beaver Lodge field, a number of deep tests have not encountered any sandstone or oil shows in cuttings of the upper part of the Qu'Appelle formation. Farther south along the anticline, about three miles northwest of the Fancy Buttes field, the Texas Company - R. Koeser (NCT#1) No. 1 well located in the NW, NW, Sec. 35, T. 151 N., R. 97 W., found less than a foot of very fine-grained sandstone with no shows of oil or gas at the top of the Qu'Appelle formation in cores of the Bakken formation-Qu'Appelle formation contact. In the North Fork field the same interval was cored in the Amerada-H. Shelvik, Tract 1, No. 1 well located in the NE, SW, Sec. 35, T. 150 N., R. 97 W., with no sandstone or shows being present. Southwest of the Madison production, the California Company - Rough Creek Unit No. 1 well located in the NW, NE, Sec. 13, T. 148 N., R. 98 W., likewise found no sandstone or shows in cores of the same interval. Southeast of the Madison production the Carter Oil Company - E. Lockwood No. 1 well located in the SE, SW, Sec. 5, T. 147 N., R. 93 W., also failed to find any sandstone or shows in cores of the top of the Qu'Appelle formation.

On the south end of the Nesson anticline in the Amerada Petroleum Corporation - C. Peck, Tract 1, No. 2 well located in the NW, NE, Sec. 27, T. 150 N., R. 96 W., the upper five feet of the Qu'Appelle formation consists of two feet of fine-grained oil stained sandstone and three feet of oil-stained sandstone and siltstone. The top of the Qu'Appelle formation is at a depth of 10, 818 feet in this well. A three hour and 42 minute drillstem test of the interval from 10,735 feet to 10,875 feet recovered 890 feet of clean water cushion, 1800 feet of slightly gas and mud cut water cushion, 185 feet of heavily gas and mud cut water cushion, and 135 feet of heavily gas cut mud. FHP: 6241, IFP: 1359, FFP: 1414, BHP: 1817.

Near the north end of the Nesson anticline shows have been noted in cuttings of the siltstone at the top of the Qu'Appelle formation in the Amerada Petroleum Corporation - C. Hanson No. 3 well located in the SW, NW, Sec. 18, T. 158 N., R. 94 W.

It appears that if, as previously mentioned, the deposition of the "Sanish" Sandstone is stratigraphically controlled by the Antelope structure, the sand may also have been deposited elsewhere along the flanks of the Nesson anticline, and especially along the east or southeast flanks of other minor structures that may be in the area, thereby forming other excellent reservoirs in these areas. We feel that these possibilities should be considered in future exploration in the area.

FIELD HISTORY

Clarence B. Folsom, Jr.

The discovery well in the Antelope-Sanish pool was the Woodrow Starr #1, drilled by Stanolind Oil and Gas Company (now Pan-American Petroleum Corporation). The well was spudded in the SW, SE of Section 21, T. 152 N., R. 94 W., on the Fort Berthold Indian Reservation in McKenzie County, North Dakota, on the 14th of June, 1953.

Surface casing (13 3/8" - 48# - S40) was landed at 491' and cemented with 400 sacks. The rotary drive bushing was 2145 feet above sea level. Drilling proceeded without incident to 6148 feet where 9 5/8" casing was landed and cemented with 200 sacks of 4% Gel and 100 sacks of neat cement. The string was a combination of 40# and 36#. Drill stem tests in the Madison producing intervals were negative and the well was taken to a total depth of 12460 feet.

A fifty sack plug was set at 12112 feet and two hundred sacks were spotted at 10900 feet. The cement was drilled out to 10610 feet. A combination string of 7" casing was set and cemented with 10 sacks of neat cement followed by a mixture of 400 sacks S10-Set with 260 cubic feet of Strata Crete and 1600 pounds of Bentonite. The string was made up of 29# N-80, 26# N-80, 23# S-95, and 23# N-80 pipe.

The casing was perforated with four Kone shots per foot from 10528-10556 feet and the well swabbed in. A sand-oil squeeze was made with the formation breaking at 4900 pounds and taking 1.2 barrels per minute at 6000 psi. Following this treatment the well flowed 65 barrels of oil in 30 minutes through a 3/4" choke. Helmerich and Payne, Inc., were drilling contractors on the well. The well was completed on December 6th 1953 after a 63 hour test yielded 1420 barrels of oil with 0.1% BS and W. The producing gas-oil ratio was 770 cubic feet per barrel. The corrected gravity of the oil was 44° API.

After considerable discussion the new pool was named "Sanish-Mississippian" and temporary spacing was set at 160 acres per well with wells to be located in the SW quarter of each quarter section. The field was defined to include the 9 sections surrounding the discovery well.

Three offsets to the discovery well proved to be disappointing from the standpoint of productivity, and no further drilling took place until June 10, 1956, when Northern Pump Company spudded its #1 Ella Many Ribs, 1/2 mile north and 1/2 mile west of the discovery well, to test the "Jefferson Sanish formation" (company terminology). The well was completed September 3rd, 1956, for 320 barrels per day after perforating with 6 holes per foot and sand-fracing. Three strings of casing were used:

10 3/4" @638/900 sx
7 5/8" @9399/600 sx
5 1/2" @10,620/75 sx

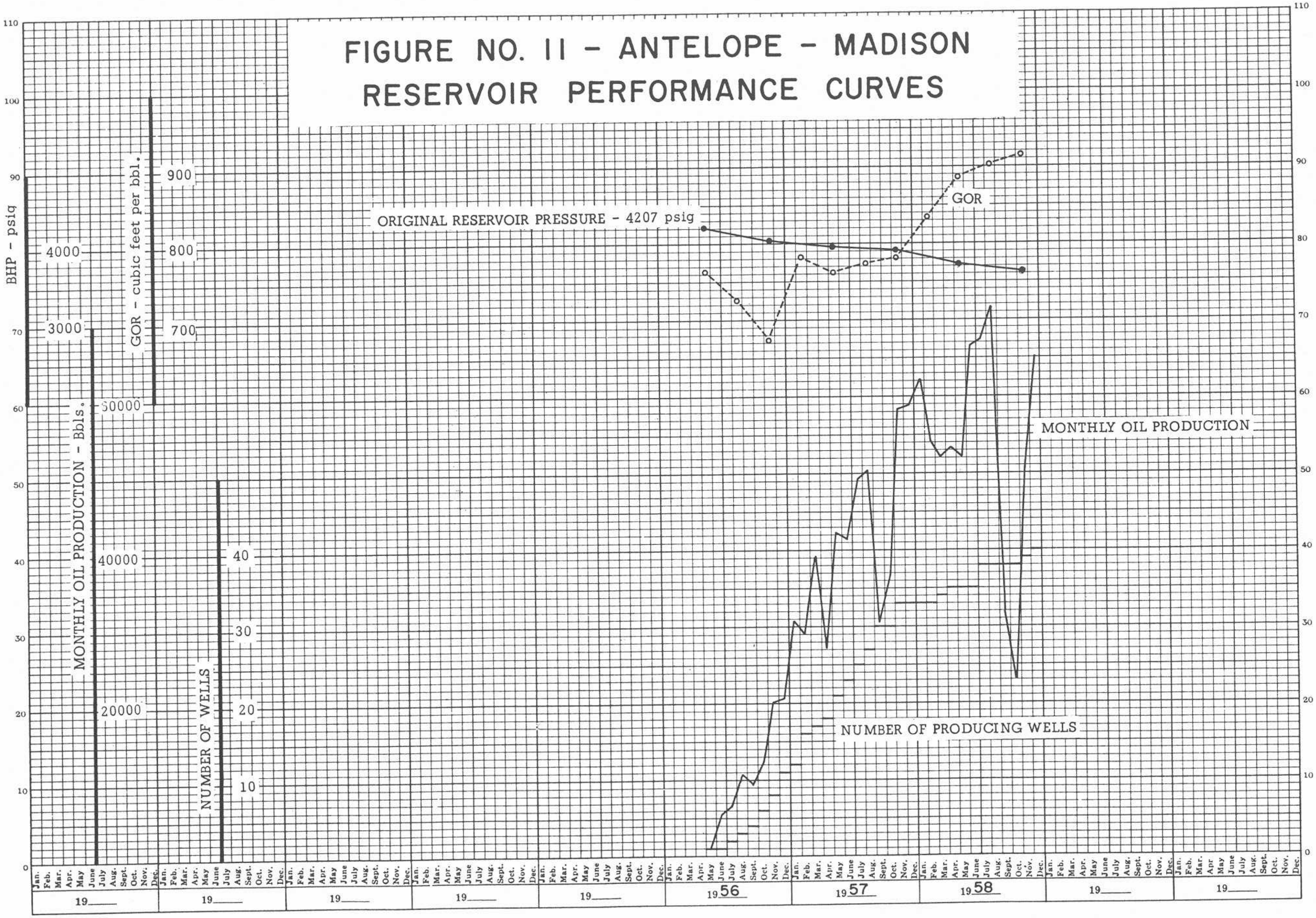


FIGURE NO. 11 - ANTELOPE - MADISON RESERVOIR PERFORMANCE CURVES two and seven-eighths tubing was run and the well flowed, with 600 psig on the tubing, through a 1/4 inch choke.

Eighty one bits were used, including two diamond core bits. The first core (10512-10571) was cut at 75 rpm with 25,000 pounds on the bit and 1000 pounds pressure on the pumps. The core consisted mainly of shale and sandstone. The second core (10571-10622) was cut @ 64 rpm with 12000 pounds on the bit and 1200 pounds of pump pressure. This core was mainly dolomite.

Drilling time was 73 days. Paul Rutledge of Santa Fe, New Mexico, was the contractor using a Bethlehem 450 rig. Ground elevation was 2159 feet with kelly bushing at 2173 feet. Maximum deviation of the hole was 2 1/2° at 5579 feet in the Ellis Group (Sundance).

Prior to spudding of the Many Ribs well, Amerada Petroleum Corporation completed its Lacey-Norby #1 in Lot 10, Section 1, T. 152 N., R. 95 W., on 12 May 1956. This was a Madison discovery and opened the Antelope-Madison pool.

The Lacey-Norby #1 was drilled in 31 days and completed for 386 barrels of oil per day, flowing through a 14/64 inch choke with 800 psi on the tubing. Producing interval was in the Madison from 9057 to 9088 feet.

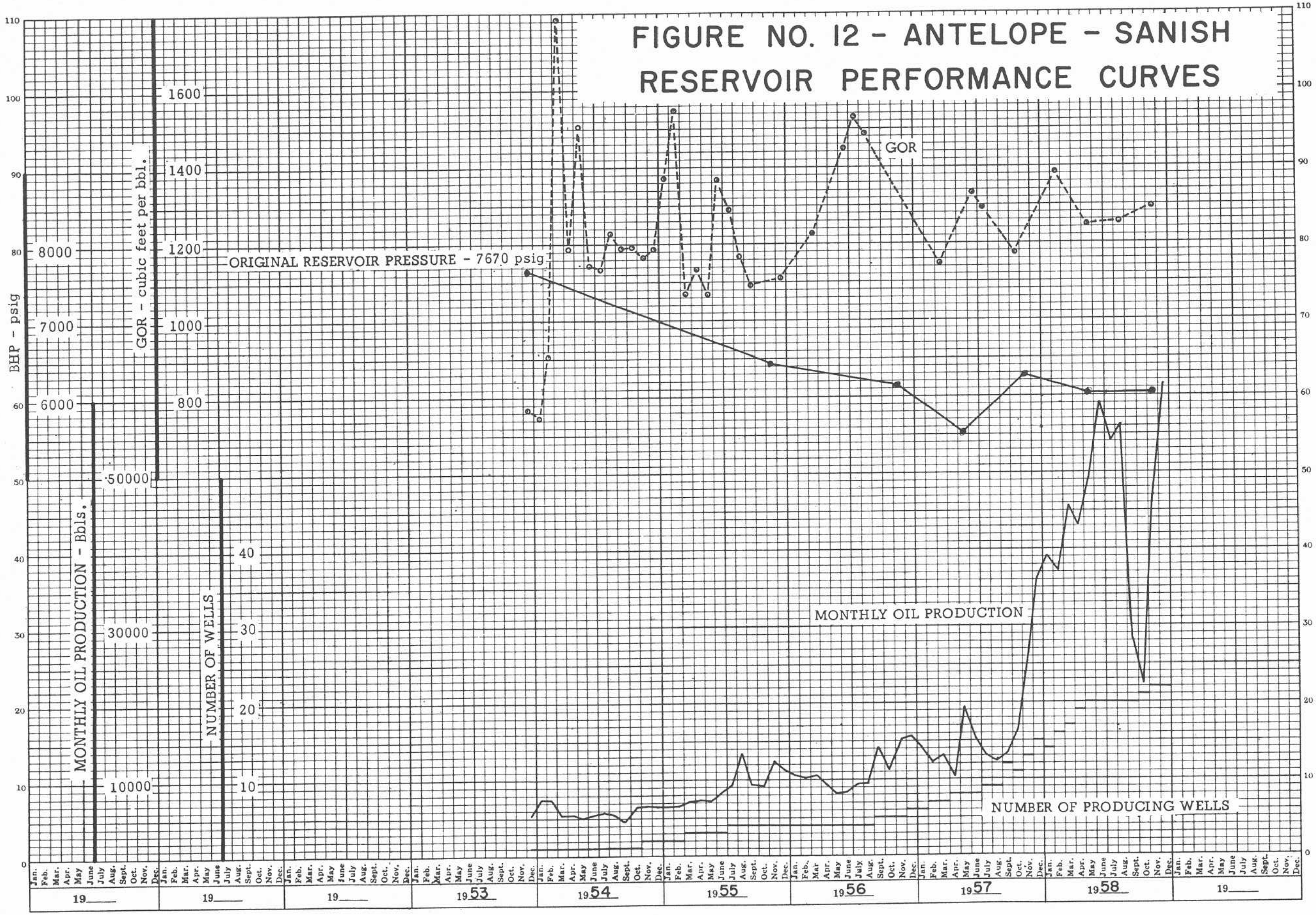
The new pool was defined, and limits set, touching the northwest corner of the "Sanish" field. Due to existence of two correction lines, the presence of a number of small lots along the reservation boundary, and the inclusion of an extra tier of lots along the northern edge of T. 152 N., a regular spacing pattern was impossible.

Spacing was set at 80 acres per well in the Madison formation with wells to be 1500 feet apart and 500 feet from a drilling unit line. The operator was allowed to designate the tracts to be included in the drilling unit provided the unit was rectangular and contained 60 acres or more.

On 13 September 1956, Northern Pump Company spudded its Gilbert T. Rohde #1 (SW, SE 17-152-94) as a "Sanish" test. A drill stem test from 9054-9130 (KB-2162 feet) feet yielded 570 feet of free oil from the Madison. Seven inch casing was set at 10504 feet with 600 sacks regular, 600 sacks Pozmix, and 260 sacks of salt, and perforated with 94 shots from 10459 to 10473 feet. Initial production was 519 barrels of oil in 27 hours through a 1/4 inch choke. On October 30, 1957, the Madison was perforated in six intervals, from 8997 to 9144 feet, and acidized with 5000 gallons. Initial production was 53 barrels of oil at 9 seventy-two inch strokes per minute.

Sixty-three days and 59 bits were required to drill the Rohde well to the "Sanish" sand. Limestone cores were cut at 75 rpm with 1000 pounds pump pressure and 18000 pounds on the bit. Dual completions were authorized under the Industrial Commission's Order #164 dated 23 May 1957.

FIGURE NO. 12 - ANTELOPE - SANISH RESERVOIR PERFORMANCE CURVES



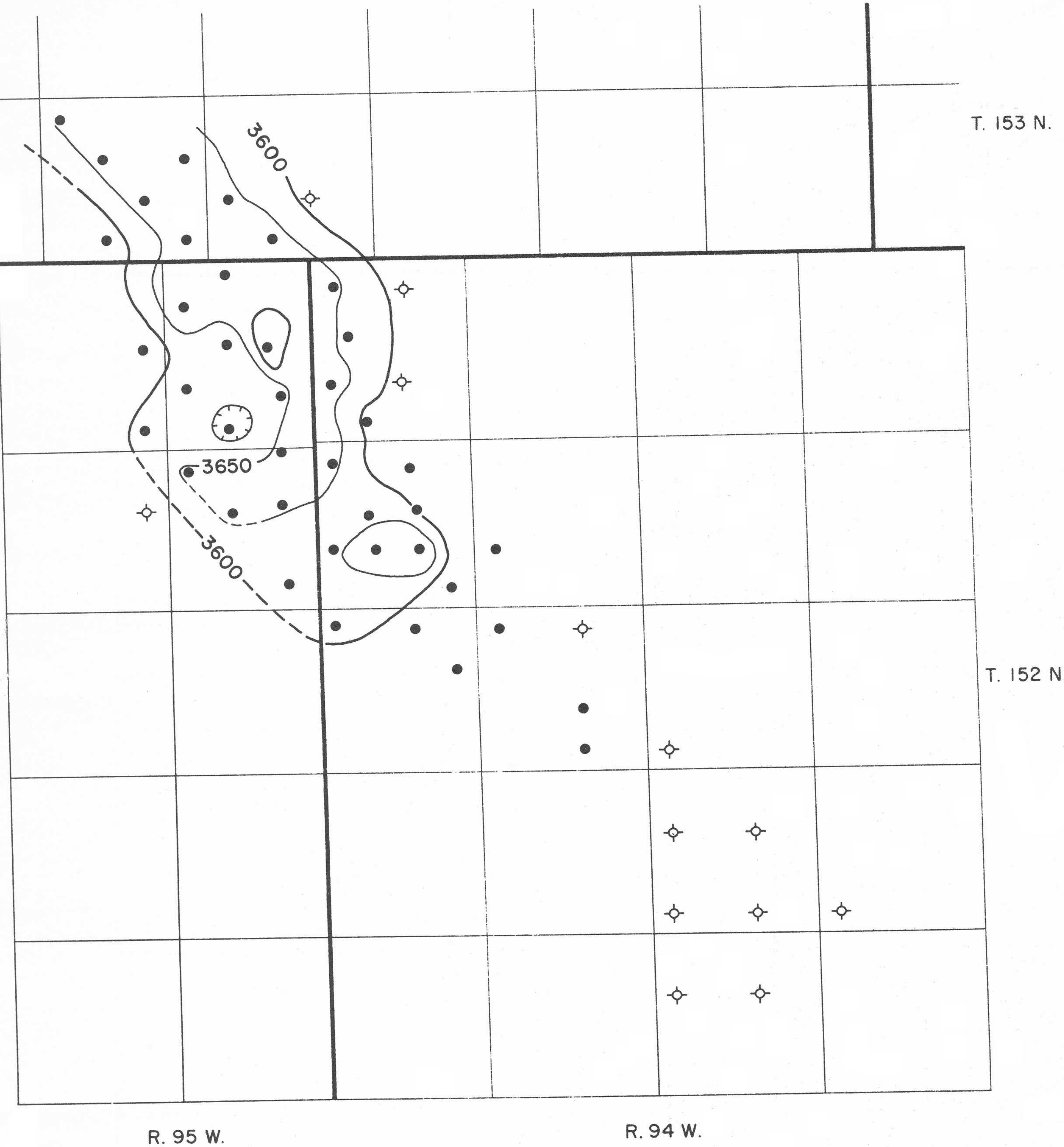


FIGURE NO. 13 - ANTELOPE - MADISON
RESERVOIR ISOBARIC MAP
NOV. 1958 (-6750)
C. I. = 25 PSIG

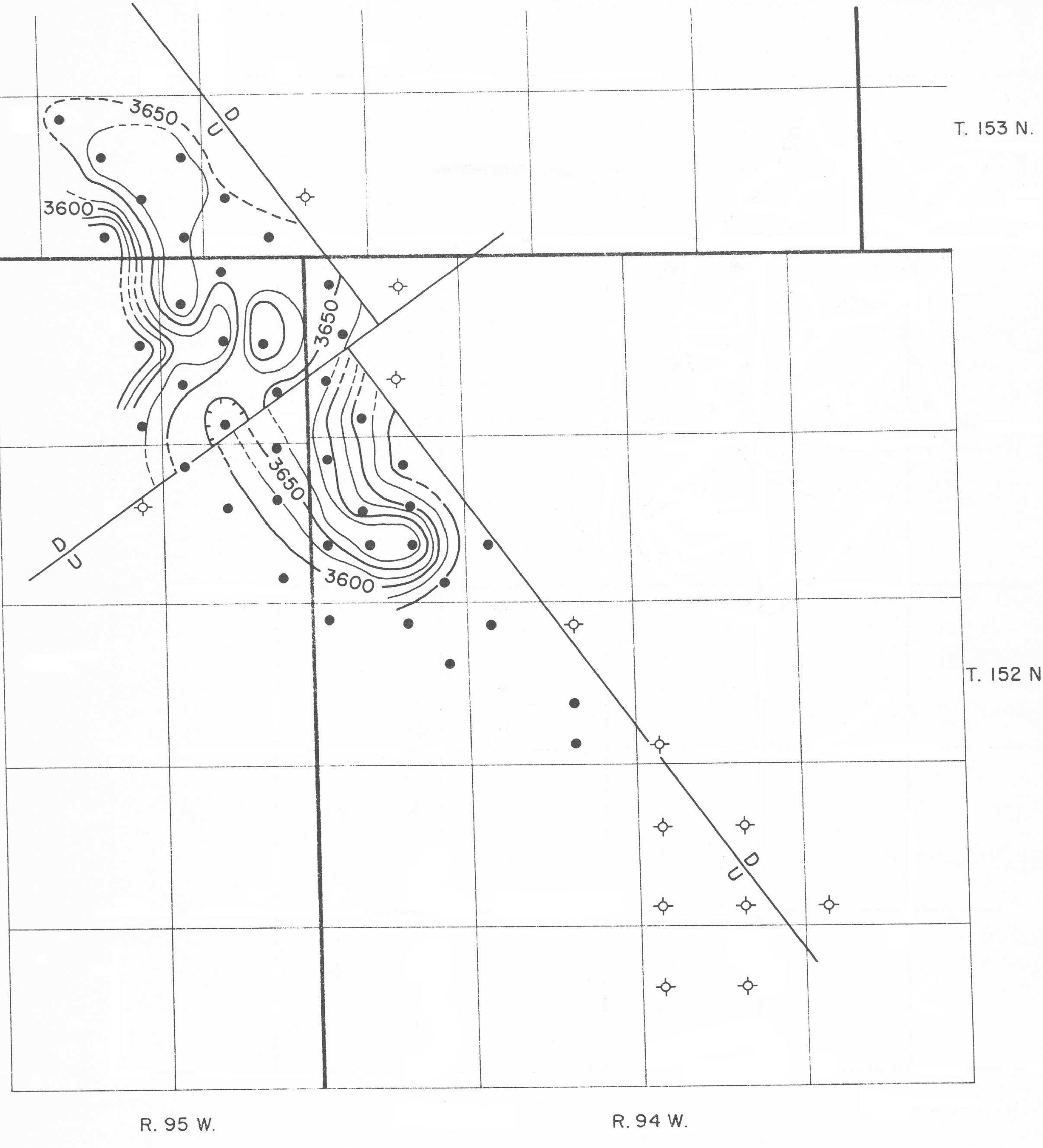


FIGURE NO. 14 - ANTELOPE - MADISON RESERVOIR
ISOBARIC MAP (FAULTING INFERRED)

NOV. 1958 (-6750)

C. I. = 25 PSIG

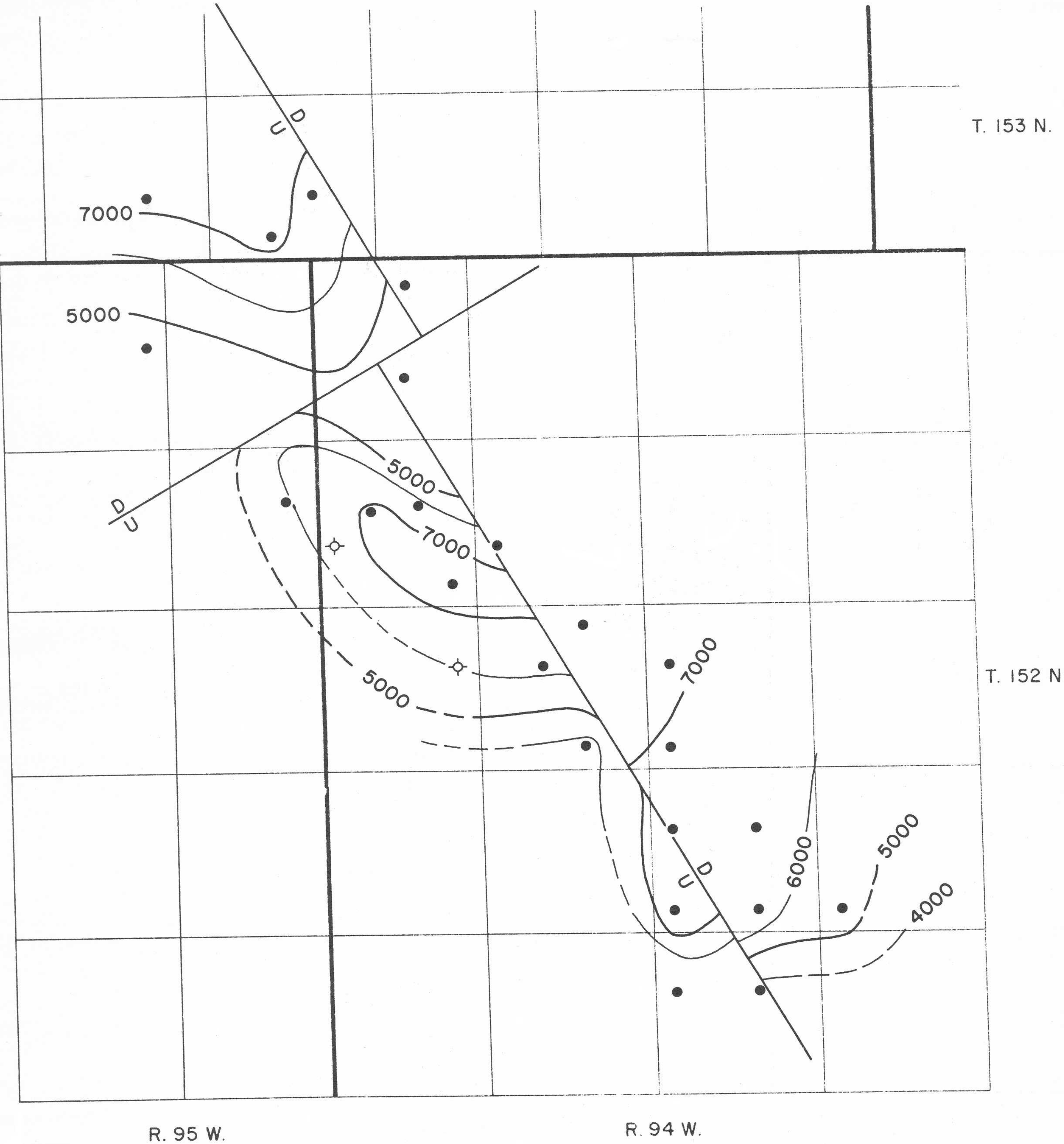


FIGURE NO. 15 - ANTELOPE - SANISH
RESERVOIR ISOBARIC MAP

NOV. 1958 (-8400)

C. I. = 1000 PSIG

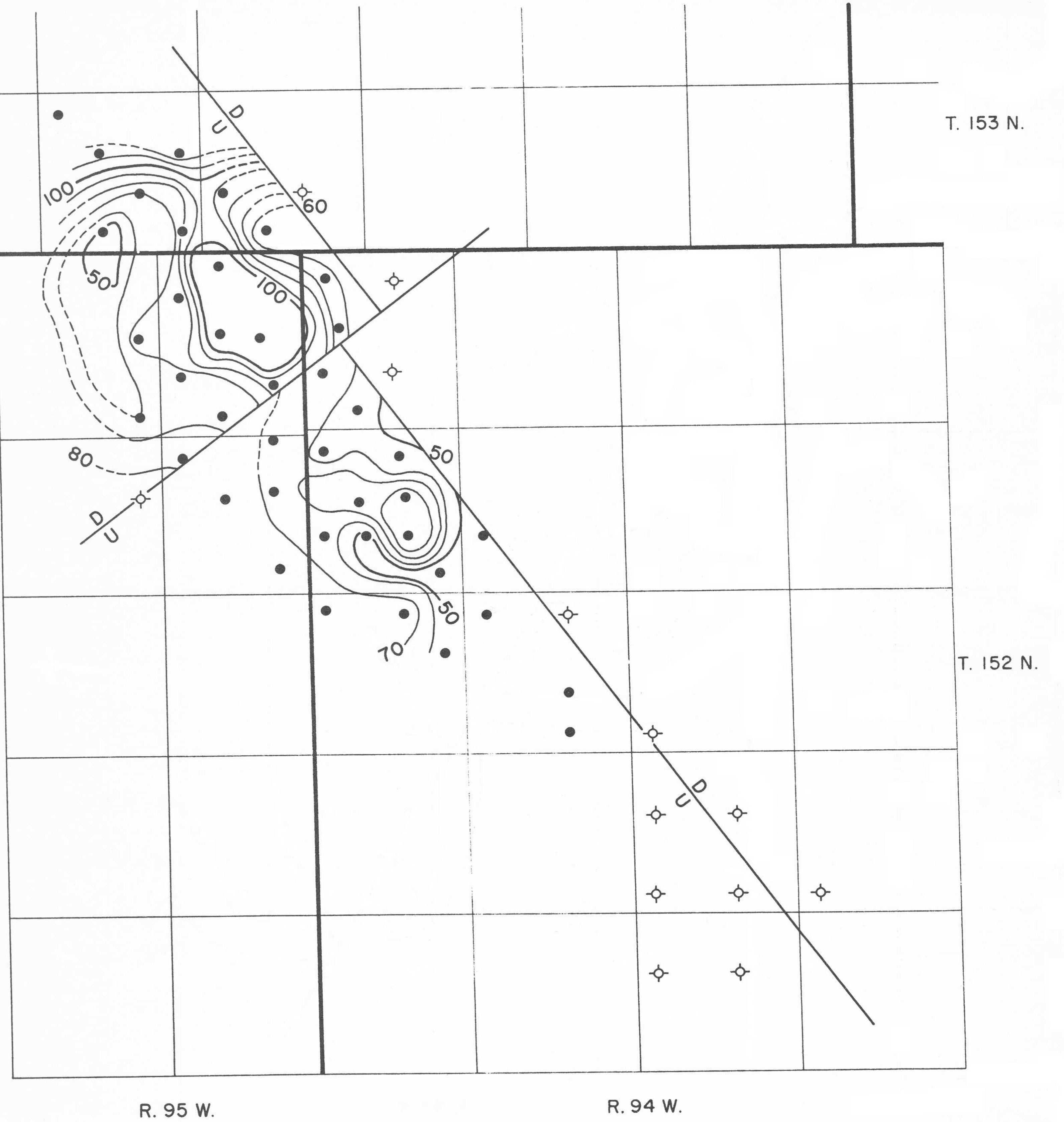


FIGURE NO. 16 - ANTELOPE - MADISON
RESERVOIR PRODUCTIVITY INDICES
MAY - NOV 1958
C.I. 10 BBLS/PSIG

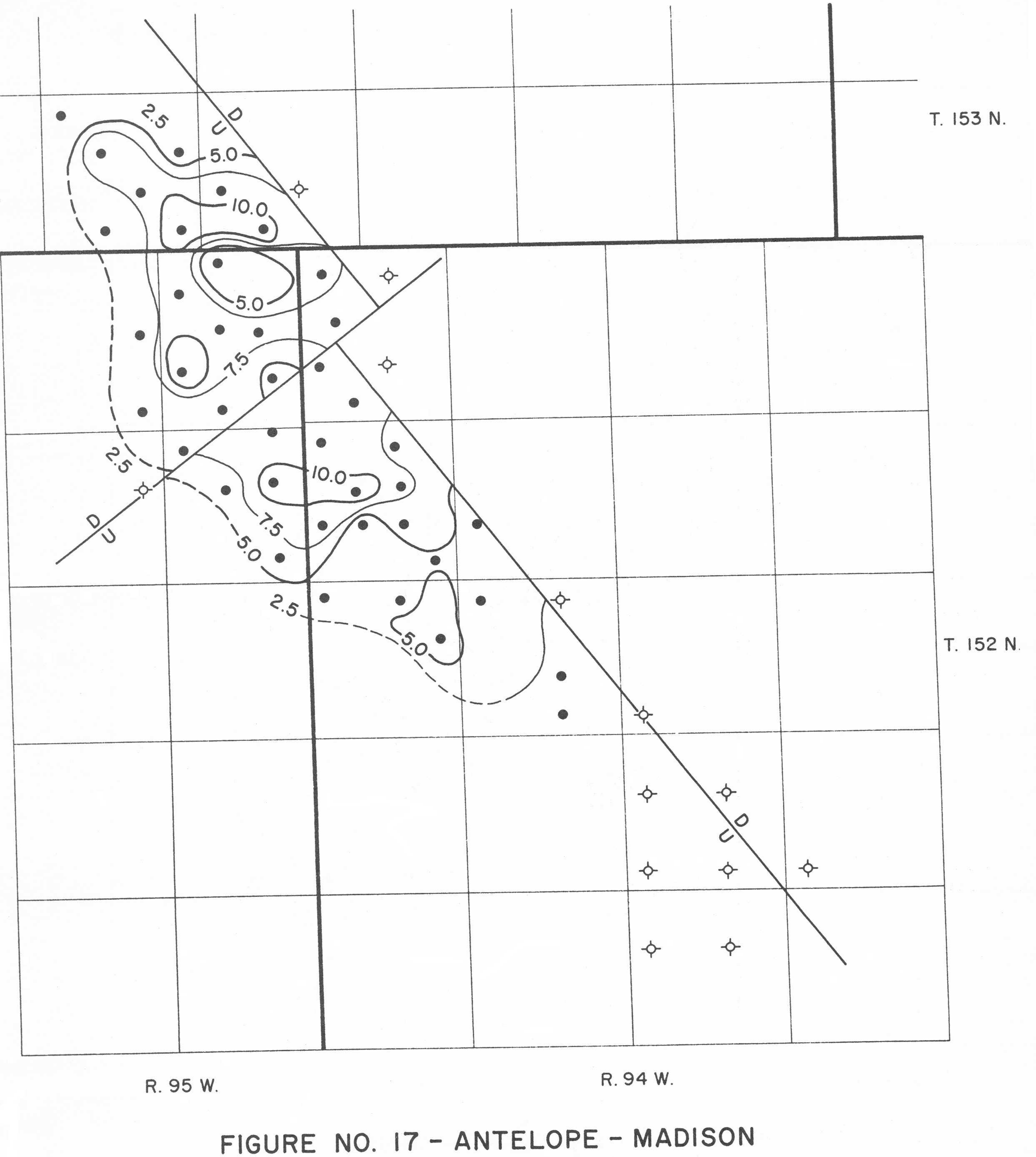


FIGURE NO. 17 - ANTELOPE - MADISON
RESERVOIR HOURLY POTENTIALS

NOV. 1958

C. I. = 2.5 BBLS/HR

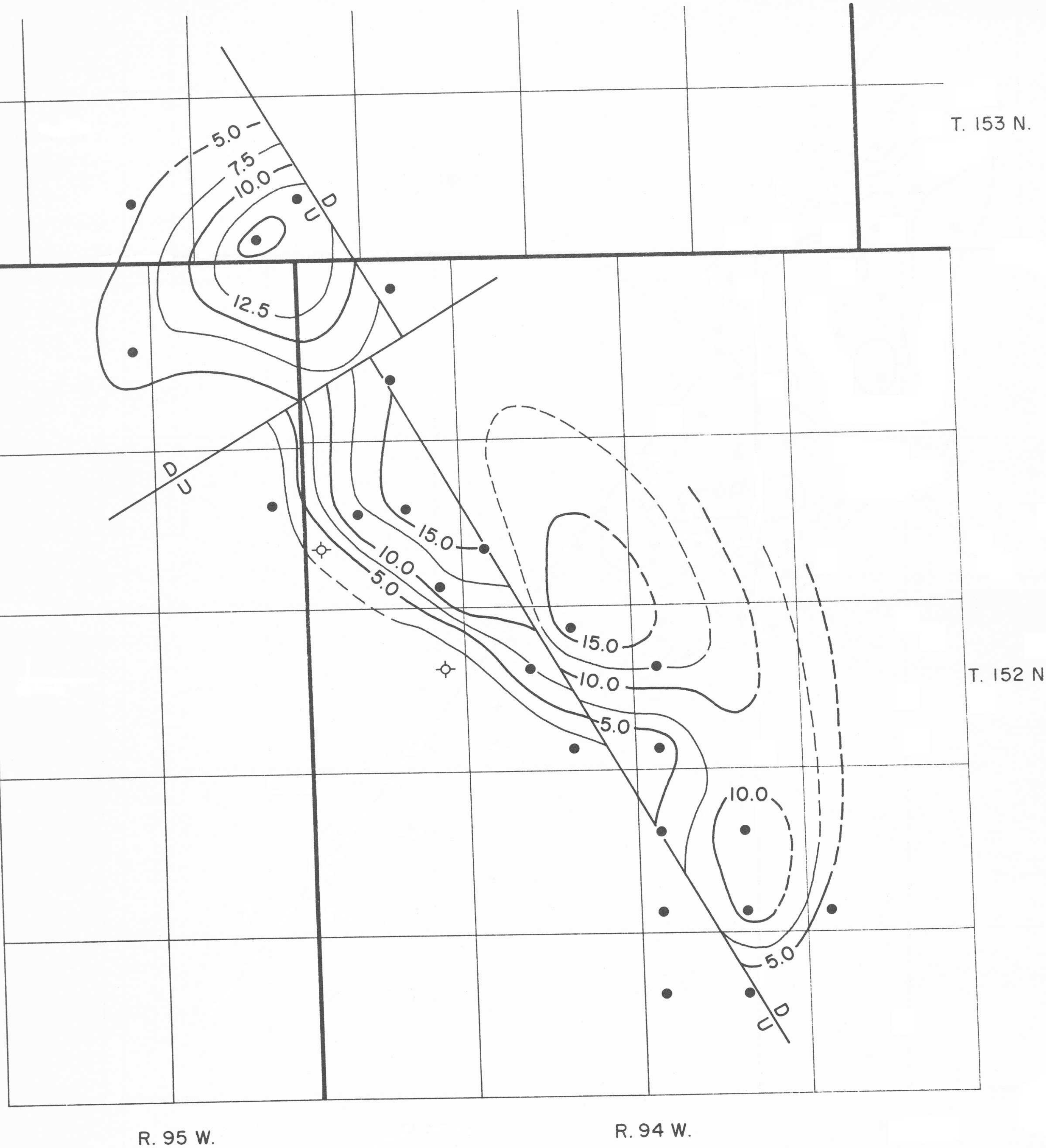


FIGURE NO. 18 - ANTELOPE - SANISH RESERVOIR HOURLY POTENTIALS

NOV. 1958

C. I. = 2.5 BBLS/HR

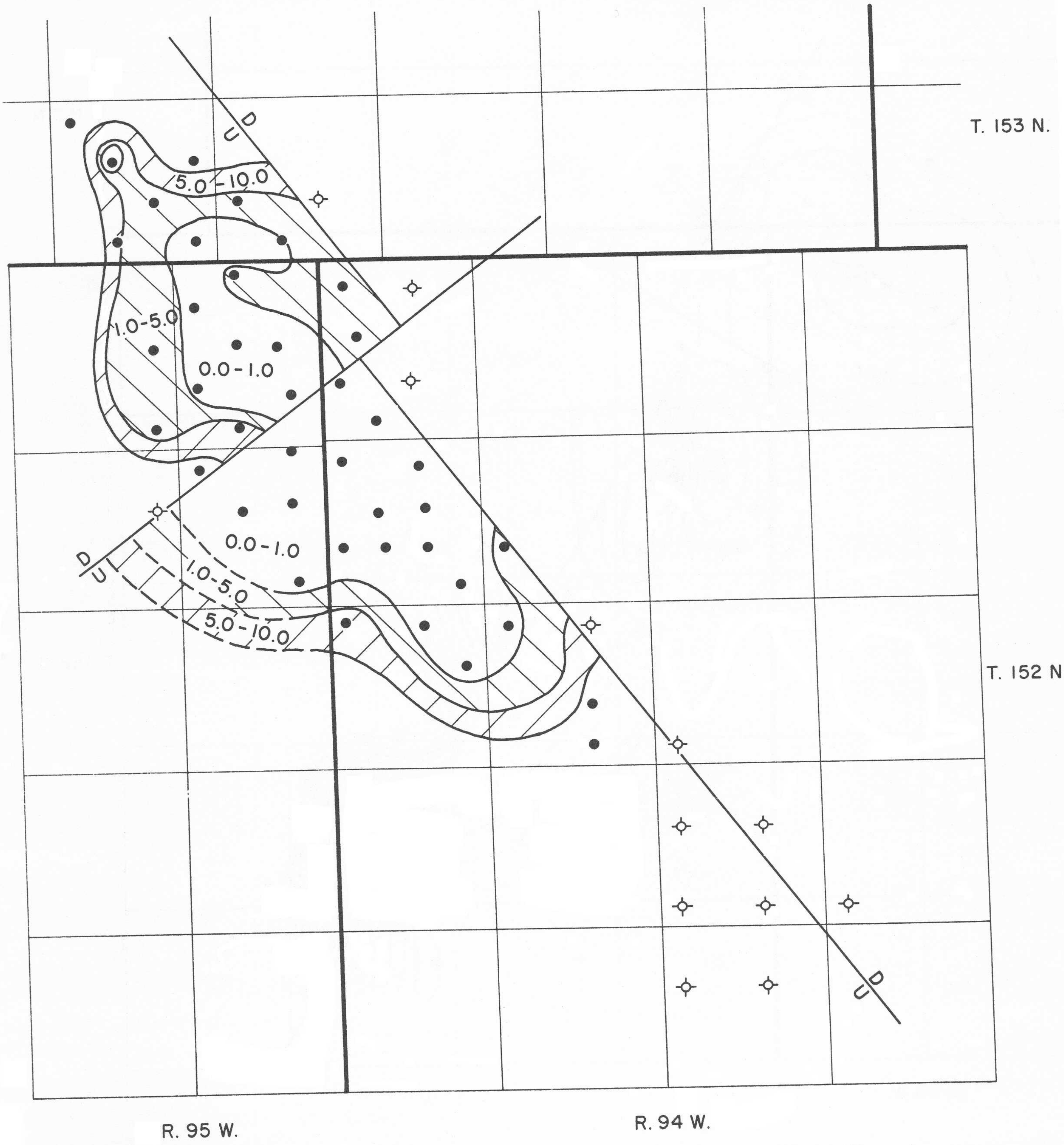


FIGURE NO. 19 - ANTELOPE - MADISON
RESERVOIR WATER PRODUCTION
H_2O AS % OF TOTAL FLUID TO 1 NOV. 1958

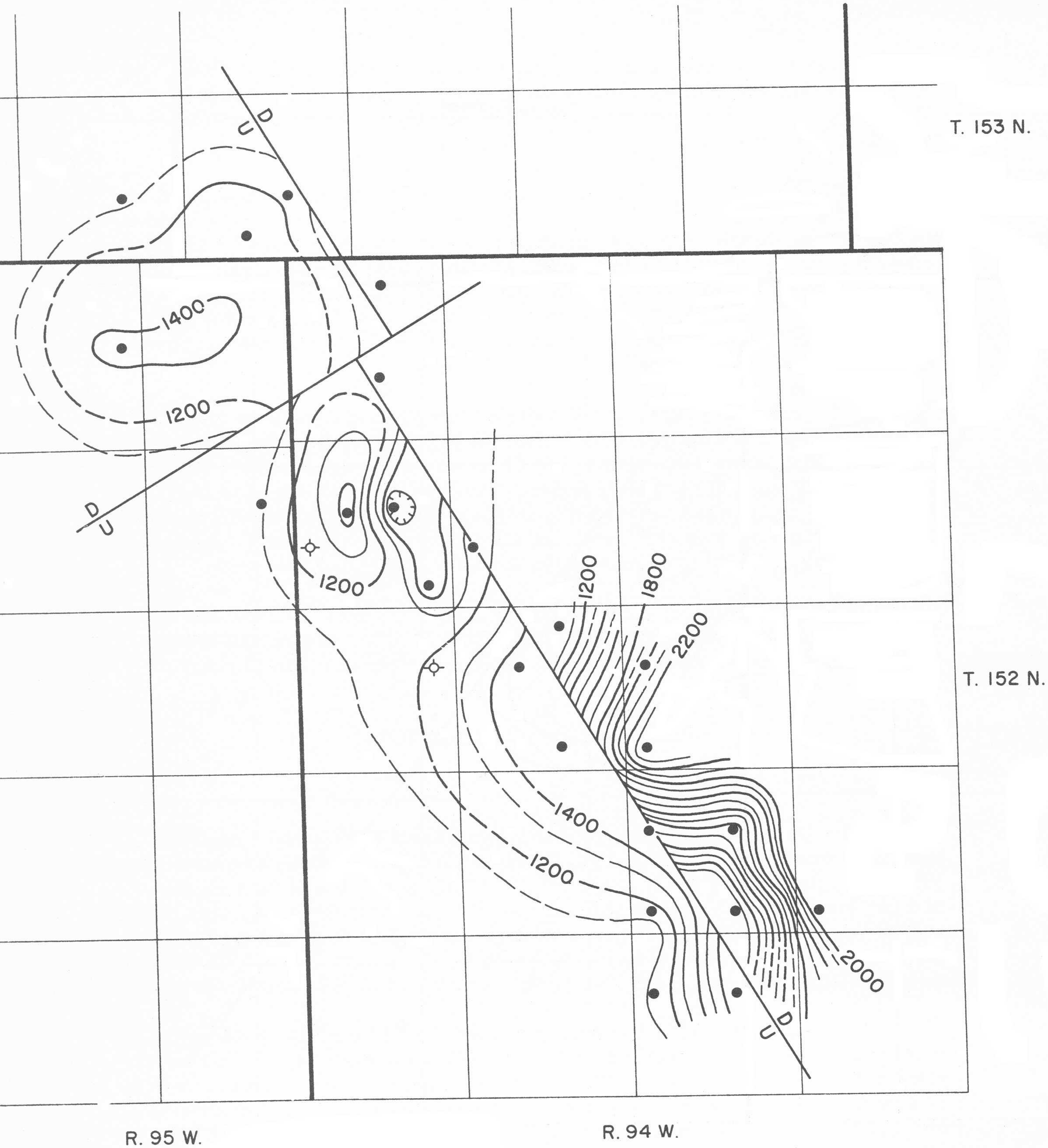


FIGURE NO. 20 - ANTELOPE - SANISH
RESERVOIR GAS - OIL RATIOS

NOV. 1958

C. I. = 100 CUFT / BBL

Due to completion of the Rohde well in the Madison limestone, the Antelope-Madison pool was extended to the southeast with section 17, T. 152 N., R. 94 W., common to both the Antelope-Madison and Sanish-Mississippian pools.

On 17 November 1957, Amerada Petroleum Corporation completed its Bancroft-Melby Unit #1 in the Sanish sand. Since the well was located in SE, NW of section 7 it was apparent that the two pools covered similar areas and on the 7th of January, 1958, the Industrial Commission redefined the Antelope field, to include the earlier Sanish field, and defined separate Madison and Sanish pools in the field. Thus the term Sanish, as a field name, disappeared from the literature, and the geologic age reference was removed from the pool name.

On August 24, 1958, the Woodrow Starr #1, the discovery well, was plugged and abandoned after extensive reworking had failed to correct casing and/or tubing difficulties. In 55 months the well produced 279,254 barrels of oil and 108 barrels of water. The pressure had declined from 7670 psig to 6635 psig at the last reading in May, 1958. Average production over the life of the well was 172 barrels of oil per day and 270 barrels per psi pressure drop. Daily productivity index was 0.637 barrels per psi.

A replacement well, the Woodrow Starr #1 A, was spudded 300 feet north of the original discovery well on August 27, 1958 and completed on October 15th with an initial production of 150 barrels of oil in 13 hours. Initial reservoir pressure, taken in November, 1958, was 6542 psig.

RESERVOIR CHARACTERISTICS

Madison Pool

The Madison producing interval consists of a fractured limestone with an average porosity of 4.75%. Connate water saturation averages about 32%. The gravity of the oil produced is 39° API and it has a Beta factor of 2.05 (estimated). Recoverable oil reserves are calculated to be 23,706,500 barrels as of 1 July, 1958. The reservoir pressure has declined from the original pressure of 4207 psig to 3632 psig in November 1958. Total production to 1 December 1958 was 1,168,740 barrels of oil and 81,682 barrels of water.

In November, 1958, the pool produced 50,727 barrels of oil and 3124 barrels of water from 39 wells in a total of 407 producing days. Due to allowable reductions as a result of a limited market, the pool produced only 34% of the month. Average production per well/day was 124.64 barrels of oil and 7.67 barrels of water. It is believed that the November production represented about 60% of present pool productive capacity.

Datum for pressure measurements was 6750 feet sea level.

Sanish Pool

The productive interval, in the "Sanish" Sand, is a silty sand with average porosity of 8.9%. Connate water saturation is approximately 33%. The oil produced in the pool has a gravity of 44° API and a Beta factor of 2.00. Saturation pressure is 2940 psig.

The reservoir pressure declined from the original pressure of 7670 psig to 6050 psig in November, 1958. Datum for the measurement was -8400 feet (sea level). However, the lower pressures are generally at the south end of the pool.

In November, 1958, the pool produced 47060 barrels of oil and 75 barrels of water from 22 wells in a total of 420 producing days. Average production per well per day was 112.05 barrels of oil. It is believed that the November production represents about 50% of the present pool productive capacity. Recoverable oil reserves were 8,935,200 barrels, as of 1 July 1958.

Total production to 1 December 1958 was 1,003,781 barrels of oil and 1027 barrels of water.

Well interference tests, in the area of the discovery well, indicate that these wells are in communication on the present spacing of 160 acres per well. In March, 1955, pressure build-up curves were made on the New Year Many Ribs #1 and the Dora Hopkins #1. The rate of build-up increased when the Woodrow Starr #1 was shut-in and halted abruptly when the Starr well was reopened. The time lag in this case was three to four days. This test demonstrated, conclusively that pressure variations are being felt throughout the reservoir and that the entire reservoir will be subject to the depletion mechanism.

Discussion:

Isobaric maps, well behavior, and structural differences in the Madison pool occasioned some discussion of possible faulting in the field. But without concrete evidence no decision was reached.

On April 9, 1957, the Director of the U. S. G. S. released, for open file, a "Structure Contour Map of the Nesson Anticline, Williston Basin, North Dakota," drawn on the top of the Mission Canyon formation by A. F. Bateman, Jr. The map showed an inferred fault, referred to as Sanish fault, running from the corner of sections 21, 22, 27, and 28 in T. 152 N., R. 94 W., northwest to the corner of T. 154 N., and 155 N., and R. 95 W., and 96 W. The fault passed to the east of Woodrow Starr #1 and Lacey-Norby #1, between these wells and their individual offsets to the east.

Upon inquiry, as to the basis for the fault, a personal communication from Chas. E. Erdmann, Regional Geologist, to Wilson M. Laird, State Geologist, Feb. 12, 1957, stated that:

"As can be seen on the map, midpoints between these pairs of wells lie on a straight line. These data could also be reconciled by a very long, narrow, sharp fold, but such a fold does not seem to conform with the character of the other minor structures as well as a fault. When Bateman and I visited Antelope Field on October 16, 1956, a quick field check in Sec. 1, T. 152 N., R. 95 W., revealed what we thought might be surface evidence of a fault."

A field party from the North Dakota Geological Survey examined the area in May, 1957, particularly the area of Section 21, but was unable to confirm the observation although a narrow valley, trending northeast through the section was observed. This valley appeared to lie at right angles to the proposed Sanish fault line.

A study of the topographic map of the area was more productive. It was noted that a line connecting the confluence of Beaver Creek and the Missouri River (33-155-96) with the confluence of Clarks Creek and the Missouri River (3-151-94), paralleled Bateman's Sanish Fault line. On the assumption that this coincidence represented the surface reflection of the fault, a more detailed examination of the area was made and it was noted that drainage east of the assumed trace was, in general, at 90° to the trace and entered the Missouri River with little or no digression from the general bearing of 90° whereas the drainage to the west of the assumed trace tended to parallel the trace before turning eastward to the river. (See fig. 1).

Of interest, also, was the configuration of the Little Missouri River in Section 15, T. 148 N., R. 97 W. On aerial photographs the bends of the river, at this point, form unusually sharp right angles, the bearings of the courses being parallel, and at right angles, to the assumed fault trace. The general configuaration of the drainage pattern throughout the area would appear to follow a general grid pattern of bearings which are N 37° W-N 53° E.

In preparing an isobaric map of the Madison reservoir it became apparent that some type of interruption of the reservoir, between the wells in the southern end and the rest of the reservoir, would be needed to present a logical picture.

A structure map on the "top of the main porosity" was prepared on the basis of a fault pattern (See fig. 11). This choice of structural hypothesis was selected since it explained, more satisfactorily, the variations in performance of wells throughout the reservoir.

The assumption of faulting, as opposed to the direct method of logical contouring, was made in view of the general situation on the Nesson anticline. Similar problems exist in all of the Nesson anticline fields. Many of the breaks between fields can best be explained by faulting. The suggested pattern (N 37° W - N 53° E) would fit well into the overall picture.

Deep drilling, north of the Missouri River has provided evidence of displacement in the Pre-Cambrian. It is felt that this basement structure is reflected in the higher sediments and that subsurface structure is, to a considerable degree, reflected in surface topography. This interpretation, if correct, would seem to indicate that the present topography, particularly south of U. S. Highway 2, has been little altered by glaciation, and that geomorphic studies might well be considered as an exploration tool in the area.

Conclusion:

From the production history, and well performance, it is concluded that both reservoirs, in the Antelope Field, are under volumetric control. Analysis of bottom-hole samples from the "Sanish" reservoir indicate a solution gas-oil ratio at saturation pressure, of 1860 cubic feet per barrel. The viscosity of the reservoir fluid is low, ranging from 1.4 millipoise, at saturation pressure, to 2.15 millipoise at original reservoir pressure. This is a desirable characteristic in view of the reservoir temperature of 244° F.

The expansibility of the reservoir fluid, at original pressure, is 4.5×10^{-6} volume per volume per psi and increases to 36×10^{-6} at bubble point pressure. This, together with the favorable viscosity, indicates high ultimate recovery.

The absence of a gas cap and the absence of water in the "Sanish" producing interval, as demonstrated by production data, indicates that the reservoir is not in communication with a large body of water. Horner extrapolations indicate that all wells are producing from a common source of supply

The Madison reservoir is being developed on an 80 acre spacing program although the pattern, as pointed out above, is not regular. In view of the assumed faulting, the irregular pattern should aid, materially, in effective drainage of the reservoir.

It is also expected that the departure from the traditional practice of locating wells according to land sub-division will be a first step toward location of wells on the basis of the geometry and geology of the reservoir.

ANTELOPE - MADISON

	Days Prod	Bbls Oil	Bbls H_2O	Average Bbls/Day/ Well	No. Wells	Arithmetic Average BHP	Aver GOR
May 1956	7	1262	0	180.28	1	4207	762
Jun	17	5540	61	325.88	1		
Jul	33	6605	273	200.15	2		
Aug	57	10950	289	192.11	3		727
Sep	52	9753	326	187.56	4		
Oct	76	12437	189	163.64	6		
Nov	90	20190	688	224.33	8	4040	673
Dec	113	20971	823	185.58	11		
	445	87708	2649				
Jan 1957	172	30913	814	179.73	12		
Feb	176	29346	862	166.74	16		781
Mar	242	39065	1865	161.43	17		
Apr	196	27199	1218	138.77	18		
May	273	42020	1506	153.92	21	3994	762
Jun	233	41884	1348	179.76	23		
Jul	355	49130	1453	138.39	25		
Aug	342	50448	1284	147.51	27		774
Sep	267	30757	750	115.19	30		
Oct	308	36971	1511	120.04	30		
Nov	422	58322	1741	138.20	33	3903	782
Dec	467	58990	1706	126.32	33		
	3453	495045	16058				
Jan 1958	448	62060	1661	138.85	33		
Feb	398	54370	1825	136.61	33		836
Mar	399	52236	2140	130.92	34		
Apr	415	53243	2156	128.30	35		
May	431	52125	1513	120.94	35	3732	888
Jun	491	66669	1820	135.78	35		
Jul	522	67458	1942	129.23	38		
Aug	557	71614	2568	128.57	38		901
Sep	289	32205	2452	111.44	38		
Oct	174	23280	1534	133.79	38		
Nov	407	50727	3124	124.64	39	3632	915
Dec	504	65063	3809	129.09	40		
	5035	651050	26544				
	8933	1233803	45251				

WOR. = .0353 bbls/bbl

ANTELOPE - SANISH

	Days Prod	Bbls Oil	Bbls H_2O	Average Bbls/Day/ Well	No. Wells	Arithmetic Aver BHP	Aver GOR
Dec 1953	23	5429	0	236.04	1	7670	770
	23	5429	0				
Jan 1954	31	7755	0	250.16	1		749
Feb	28	7686	0	274.50	1		911
Mar	29	5482	0	189.03	1		1784
Apr	30	5515	0	183.83	1		1196
May	31	5047	0	162.81	1		1506
Jun	30	5360	0	178.67	1		1147
Jul	31	5767	0	186.03	1		1138
Aug	31	5254	0	169.48	1		1231
Sep	30	4622	0	154.07	1		1195
Oct	28	6171	0	220.39	1		1197
Nov	60	6809	0	113.48	2		1166
Dec	62	6784	0	109.42	2		1187
	421	72252	0				
Jan 1955	62	6754	0	108.94	2		1376
Feb	56	6829	0	121.95	2		1554
Mar	57	7123	0	124.96	3		1062
Apr	86	7307	0	84.97	3		1135
May	90	7305	0	81.17	3		1063
Jun	87	8281	0	95.18	3		1362
Jul	119	9240	0	77.65	4		1295
Aug	124	13516	0	109.00	4		1165
Sep	79	9514	5	120.43	4	6443	1097
Oct	123	9046	0	73.54	4		
Nov	120	12038	0	100.32	4		
Dec	124	11433	0	92.20	4		1111
	1127	108386	5				
Jan 1956	124	10754	0	86.73	4		
Feb	116	10368	0	89.38	4		
Mar	123	10556	0	85.82	4		1216
Apr	120	9542	0	79.52	4		
May	124	8284	0	66.81	4		
Jun	119	8521	0	71.61	4		1452
Jul	124	9494	0	76.56	4		
Aug	124	9653	0	77.85	4		
Sep	148	14152	10	95.62	5		1533
Oct	152	11286	10	74.25	5		1483
Nov	148	15020	13	101.49	5	6179	
Dec	170	15709	9	92.41	6		
	1592	133339	42				

ANTELOPE - SANISH (cont.)

	Days Prod	Bbls Oil	Bbls H_2O	Average Bbls/Day/ Well	No. Wells	Arithmetic Average BHP	Aver GOR
Jan 1957	186	14158	9	76.12	6		
Feb	187	12304	10	65.80	7		
Mar	217	13213	12	60.89	7		1150
Apr	199	10409	13	52.31	8		
May	240	19419	13	80.91	8	5625	
Jun	224	15003	11	66.98	8		1339
Jul	239	13096	12	54.79	9		
Aug	232	12457	14	53.95	9		1299
Sep	246	13649	16	55.48	12		
Oct	274	16522	25	60.30	11		
Nov	246	25062	75	101.88	13	6287	1173
Dec	373	36375	81	97.52	15		
	2863	201667	291				
Jan 1958	360	39066	71	108.52	14		
Feb	336	37119	39	110.47	16		1386
Mar	395	45844	51	116.06	17		
Apr	440	43367	70	98.56	19		
May	441	49324	98	111.85	20	6028	1251
Jun	487	59006	52	121.16	20		
Jul	454	54223	77	119.43	20		
Aug	469	56391	56	120.24	20		1266
Sep	349	28417	93	81.42	20		
Oct	314	22891	84	72.90	21		
Nov	420	47060	75	112.05	22	6050	1294
Dec	497	61553	72	129.09	22		
	4962	544261	838				
	10988	1065334	1176				

WOR = .0011 bbls/bbl

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