UPDATE ON DRAINHOLE DRILLING
EMPIRE ABO

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INTRODUCTION

ARCO Oil and Gas Company has completed six drainhole wells in the Empire Abo Unit and plans to complete four more in early 1984. A drainhole well is one in which the wellbore has been deviated from vertical to horizontal with a turn radius of 20 to 30 ft. The horizontal hole extends up to 200 ft. Figure 1 illustrates an ideal drainhole completion. The increased surface area open to flow in the oil column reduces the susceptibility to gas coning as compared to conventionally completed wells. "Conventional Well" refers to a cased, vertical wellbore which has been perforated and acidized, (Fig. 2). A density-controlled acid job is generally used when stimulating to prevent etching upward to the gas cap. Even with the density-controlled method, significant upward etching occurs, increasing the susceptibility to gas coning.

Initially, new wellbores were drilled for the drainhole completions. Recently a technique was devised and tested in the field to complete existing cased wellbores as drainhole wells. The main advantage of this new procedure is a substantial saving in drilling and completion costs.

This paper summarizes the observed performance of the drainhole wells. A basic outline of the procedures used to drill the first six drainhole wells is included.

FIELD HISTORY AND GEOLOGY

The Empire Abo field is located 8 miles southeast of Artesia, New Mexico in Eddy County, (Fig. 3). The Unit produces from a transgressive carbonate barrier reef buildup of lower Leonard (Permian) age. This reef is one of several in a long trend flanking the northern edge of the Delaware basin. The productive reef is approximately 12½ miles long and 1½ miles wide. Average depth of the reef is 5800 ft and the thickness averages 300 ft, (Fig. 4).

The trapping mechanism at Empire is both stratigraphic and structural. The reef dips below the oil/water contact to the south and east. Permeability and porosity fail to the north and west as a result of carbonate muds, green shales, and anhydrite inclusions.

Porosity development is erratic and cannot be correlated between wells. Porosity is the result of leaching of abundant detrital fossil fragments, dolomitization, and recrystallization. The best porosity development is found in the reef core. There is no apparent intercrystalline porosity.

Vertical fracturing, which is responsible for the characteristic performance of the reservoir, is apparently due to local slumping as well as large scale settling and some tectonic activity. Fracture orientation is generally 0 to 45 degrees from vertical and is parallel to the reef trend. These fractures link up the erratic porosity development and provide excellent pressure communication in the reservoir.

Approximately 97 percent of the Empire Abo field was unitized into the ARCO Oil and Gas operated Empire Abo Unit in October 1973. Extensive reservoir model calculations indicated a substantial increase in oil recovery could be achieved by unitizing rather than continuing competitive primary depletion. Under unitized operations updip wells producing from the gas cap are shut in to conserve reservoir energy. Oil is produced by downdip wells, thus minimizing free gas production. Residue gas injection began in June 1974.

An engineering study completed in 1975 determined ultimate oil recovery would be increased by selective infill drilling on 20-acre spacing. A subsequent study completed in 1977 determined further increases in oil recovery would result from selective infill drilling on 10-acre spacing. A total of 158 infill wells were drilled based on these two studies.

Field performance is shown in Figure 5. Basic reservoir data are listed in Table 1.

GAS CONING

A large, secondary gas cap has formed as the reservoir has been depleted. Free gas production from this gas cap occurs due to gas coning, (Fig. 6). Production of free gas wastes reservoir energy and substantially reduces oil production because of the relative permeability characteristics of the reservoir. Figure 7 illustrates the impact of gas coning on the performance of a conventional well.

Gas coning is by far the most serious problem facing the working interest and royalty owners in the Empire Abo Unit. Unitization, gas injection, and infill drilling are all examples of projects undertaken in the past to delay gas coning in the field. In addition to these projects workovers to recomplete producing wells as low in the reservoir as possible have been ongoing in the field. Many wells producing free gas have been returned to solution GOR production by completing lower in the oil column. Virtually all opportunities for this type of workover have been exploited. Completing near the base of the reservoir is not always possible as the pay is much tighter and often will not produce at economical rates. Drainhole drilling is currently being evaluated as a less conventional means of controlling gas coning.

DRAINHOLE DRILLING REVIEW

Drilling

ARCO Oil and Gas has completed six drainhole wells in the Empire Abo Unit. In order of completion they are: K-142, J-213, J-241, K-211, G-301, and F-354, (Fig. 8). The first four drainholes were drilled as new wells, and the last two were drilled out of existing wellbores.

The first three drainholes completed in the Unit were each drilled out of open holes. The configuration of the vertical wellbores for these drainhole wells is shown in Figure 1. A 6-in. open hole extends below an 8-3/4-in. hole which is cased with 7-in. casing. Prior to setting the 7-in. casing open hole logs and DST's were used to determine the kickout point of the drainhole. The turn to horizontal was made by drilling off a whipstock with an angle-building assembly on flexible drill collars, (Fig. 9). After the hole was turned to horizontal, a stabilized assembly was run to drill the drainhole out into the formation. The length of the horizontal hole drilled in each well was: K-142, 106 ft with 49 ft of closure and, 43 ft with 19 ft of closure (2 drainholes); J-213, 122 ft with 107 ft of closure; J-241, 159 ft with 146 ft of closure. Closure is the horizontal distance from the vertical wellbore to the end of the drainhole.

The fourth drainhole drilled, the K-211, proved the mechanical feasibility of drilling a drainhole out of a cased wellbore. Seven-inch casing was set through the kickout point in the K-211. The drainhole was kicked out of the wellbore by milling a 10-ft section of the casing, orienting and setting a whipstock, and then running the angle-building assembly and drilling out into the formation through the milled section of the casing. Approximately 175 ft of drainhole were drilled with a closure of 158 ft.

Having proved the feasibility of kicking out through a cased wellbore, ARCO Oil and Gas selected two existing wells for drainhole completions. Only one wellbore, the G-301, has large enough casing to apply the procedure used to drill the K-211. The G-301 is cased with 7-5/8-in. casing while virtually every other wellbore in the Unit is cased with 5½ in. casing. A new procedure for making a cut in 5½-in. casing was devised and tested in the F-354. Future drainhole completions will probably be accomplished using the same general procedure as was used to complete the F-354 drainhole.

Rather than milling an entire section of casing as was done in the K-211, a "window" was cut in the F-354 casing by milling off of a whipstock. The turn to horizontal was made through this window using an angle building assembly on flexible drill collars, (Fig. 9). Ideally, the drainhole turns to horizontal within a turn radius of about 30 ft (Fig. 1). Unfortunately, the F-354 drainhole made a sharp turn, down to vertical, approximately 30 ft from the cased wellbore. Drilling continued until the torque on the drill string became excessive. The maximum angle achieved was 89 degrees after drilling 88 ft of spiraling hole with a closure of 42 ft. The window cutting procedure worked quite well in the F-354. Problems encountered while attempting to turn to horizontal are believed to be due to reservoir heterogeneities.

The same procedure was used to mill the casing and drill the G-301 drainhole as has been described for the K-211 drainhole. Approximately 200 ft of drainhole were drilled with a closure of 183 ft.

Stimulation

Only two drainhole wells required stimulation. Both the J-213 and J-241 drainholes were drilled into extremely tight pay. The porosity at the kickout point is approximately 3 percent in both wells. Numerous acid/xylene washes were used to clean the wellbore faces and stimulate the wells. All six of the drainholes were treated with a solvent to clean out the mud cake.

Cost

Substantial cost savings were realized by completing existing wells as drainholes rather than drilling new wells, (Table 2). The estimated cost to complete the four drainholes scheduled for 1984 is 350 M$ per well. The cost to drill new wells for drainhole completions was approaching 1 MM$ per well. This significant reduction has encouraged the Unit to pursue a selective drainhole recompletion program.

Orientation

Future drainhole completions will be oriented N20°W or S20°E, perpendicular to the fracture trend of the reservoir. All of the drainholes drilled thus far, with the exception of the K-142, have been drilled in the northwest quadrant at approximately N70° W. This is apparently the path of least resistance. Drilling N20°W or S20°E will intersect more fractures than drilling N70°W. By intersecting more fractures, higher rates and recoveries should be obtained.

ARCO Oil and Gas has experienced some difficulty preventing the drainholes from climbing up toward the gas cap. This is probably due to the fracture orientation of 0 to 45 degrees from vertical. Drilling S20°E should alleviate this problem. It appears the fractures dip to the northwest, which causes the drill bit to climb when drilling toward the northwest. Drilling southeast should cause the bit to turn downward. The stabilized assembly should help achieve a horizontal drainhole by counteracting the tendency to lose angle. The key to determining whether to drill N20°W or S20°E is the location of the well. In areas near the water oil contact, on the south and east edges of the field, it is more desirable to drill N20°W, away from the water.

PERFORMANCE SUMMARY

Four of the six drainholes in the Empire Abo Unit have displayed superior GOR performance as compared to conventional wells. The J-213 and J-241 have produced for over 2½ years at or near the solution GOR. The K-142 produced at the solution GOR for about 1 year before free gas production began. The K-142's oil rate declined with the onset of free gas production, but this decline has been at a substantially lesser rate than conventional wells suffering the effects of gas coning. The G-301, which had been producing at high GOR's from a conventional completion, was returned to low GOR production by the drainhole completion. Table 3 and Figures 10 through 15 summarize the performance of all six drainholes. The disappointing performances of the K-211 and F-354 are believed to be due to the proximity of these two drainholes to free gas in the reservoir.

The J-213 and J-241 provided a rigorous test of the ability of drainholes to resist gas coning. Offset wells, drilled during the infill drilling program, coned gas almost immediately after completion. The ability of the two drainhole wells to resist gas coning indicates the effectiveness of drainhole completions at producing oil at or near the solution GOR from areas in which conventional completions are ineffective.

The K-142 provides an indication of the impact of free gas production on drainhole wells. Figure 7 illustrates the performance of a typical conventional well which has coned gas. The decline rate is often greater than 100 percent per year. The decline rate of the K-142 has been much less severe. The superior GOR performance is attributed to the large surface area open to the formation and to the numerous fracture systems intersected by the drainhole.

Free gas production occurred immediately upon completion of both the K-211 and the F-354 drainholes. In the case of the K-211 this is attributed to the proximity of the end of the drainhole to the gas/oil contact. The drainhole was drilled past horizontal and climbed, coming within 36 ft of the gas-oil contact. Ordinarily, a standoff of 80 ft is desired. The susceptibility to coning is a strong function of this standoff distance. The performance of the K-211 emphasizes the importance of controlling drainhole climb in future completions.

Free gas is almost certainly entering the F-354 drainhole near the cased wellbore. A gas cone was already present from the previous conventional completion. An attempt had been made to block the gas cone from flowing into the producing perforations of the conventional completion by injecting a sealant into the formation near the wellbore. Unfortunately the flow of oil was also blocked off and the well had to be shut in. Drilling a drainhole out through the plugged formation and into clean reservoir was thought to be an ideal method of returning the F-354 to low GOR oil production. The drainhole only penetrated the reservoir rock a distance of 42 ft from the cased wellbore, however. An important conclusion drawn from the F-354 drainhole is that the gas cone at the cased wellbore must be prevented from communicating with the drainhole. This was successfully accomplished in the G-301 drainhole by injecting a large volume of sealant into the drainhole near the vertical wellbore. Future drainhole completion procedures will certainly include this step.

FUTURE PLANS FOR DRAINHOLES

Four drainhole completions are scheduled for 1984. The information gathered from these completions along with data from the existing drainholes will be used to evaluate the impact of drainhole wells on the ultimate recovery of the Empire Abo Unit.

CONCLUSIONS

1. Drainhole wells are less susceptible to gas coning than conventional wells.
2. Completing existing wells as drainholes is mechanically feasible and more cost effective than drilling new wells.
3. The full impact drainhole wells will have on the ultimate recovery has not yet been evaluated.

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REFERENCES

LeMay, W. J.: "Abo Reefing in Southeastern New Mexico", paper presented at the Third Annual Southwestern Federation of Geological Societies Meeting, Abilene, Texas, October 12-14, 1960.

Stramp, R. L.: "The Use of Horizontal Drainholes in the Empire Abo Unit", Paper 9221 presented at the 1980 Fall Technical Conference and Exhibition of the SPE of AIME, Dallas, Texas, September 21-24, 1980.

Table 1
Empire Abo Unit Reservoir Data Summary

General	
Discovery	November, 1957
Well Status - November 1983	
Producers	228
Injectors	23
Shut In	145
Current Status - November 1983	
Unit Allowable, (BOPD)	7574
Oil Producation, (BOPD)	7202
Gas Production, (MCFD)	61329
Producing GOR, (CF/BO)	8516
Gas Injection, (MCFD)	36612
Water Production, (BWPD)	7228
Average Depth to Top Reef, Feet	5767
Productive Acres	8993
Formation	
Type Rock	Vugular Dolomite
Average Net Pay Thickness, Feet	183
Average Porosity, % (Log Data)	6.4
Water Saturation, %, Main Reef	20.0
Original Gas-Oil Contact, Feet subsea	-1750
Original Water-Oil Contact, Feet subsea	-2665
Reservoir mid-point, Feet subsea	-2264
Reservoir Fluid	
Original Reservoir Pressure, psia at -2264'	2359
Reservoir Pressure at Bubble Point, psia at -2264'	2231
Oil Formation Volume Factor, RVB/STB at Pbp	1.606
Gas Formation Volume Factor, RVB/SCF at Pbp	.00098
Gas in Solution at Pbp SCF/STBO	1250
Oil Viscosity at Pbp, centipoise	0.387
Reservoir Volumetric Data	
Original Oil-in-Place, (MMSTBO)	383.2
Original Gas-in-Place, (BCF)	483.4

Table 2
Horizontal Drainhole Drilling Costs

Drainhole Well Name	Completion Date	Completed Cost (M$)
K-142	10/14/79	638
J-213	9/27/80	883
J-241	4/28/81	965
K-211	7/28/81	944
F-354	8/12/83	183*
G-301	5/31/83	272

*Estimated cost

Table 3
Horizontal Drainhole Performance Summary

	Initial Performance		Drainhole Cumulative Production*		
Drainhole Well Name	Oil (BOPD)	GOR (MCF/STB)	Oil (MBO)	Water (MBW)	Gas (MMCF)
K-142	200	0.3	195	3	340
J-213	15	0.6	27	0	22
J-241	50	0.7	54	8	35
K-211	100	3.0	32	2	259
F-354	36	6.3	9	1	46
G-301	72	1.6	17	0	24

*Cumulative Production is Through November 30, 1983.

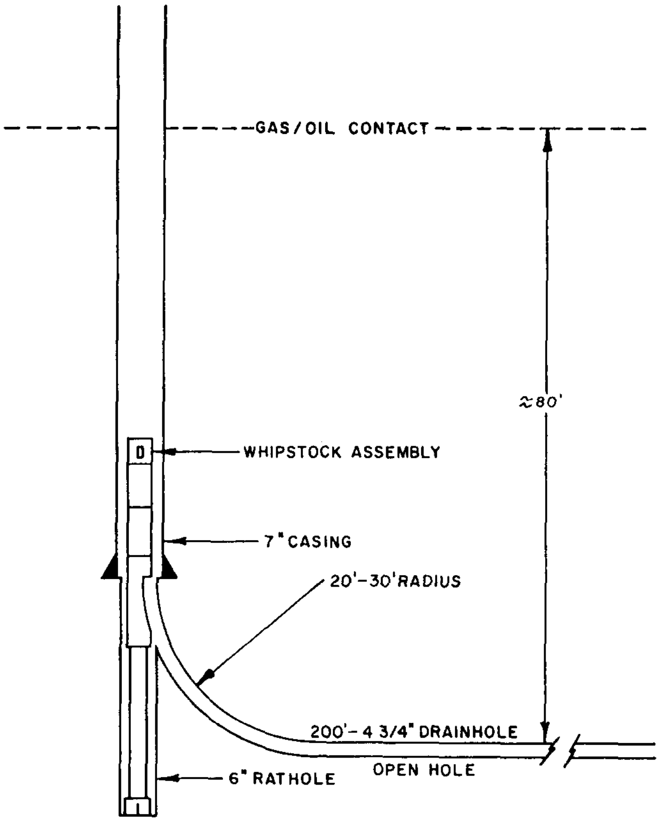

Figure 1 - Ideal Empire Abo drainhole completion

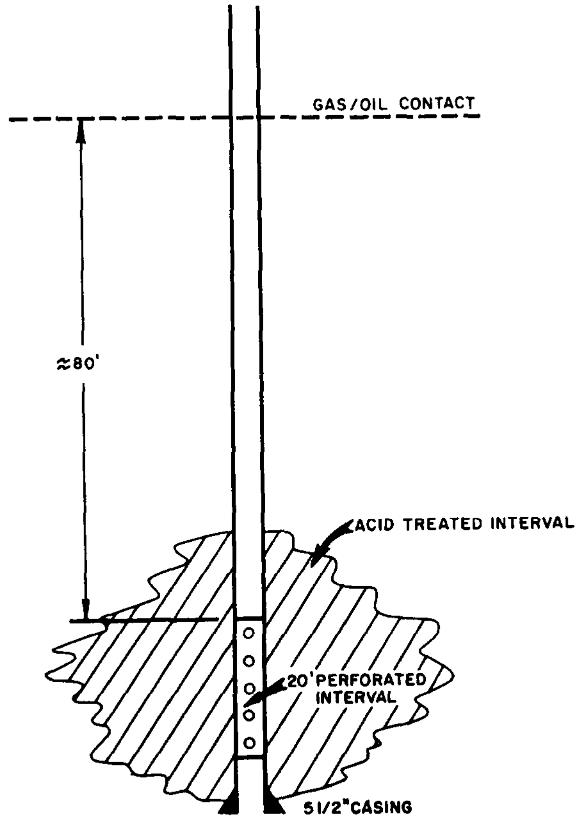

Figure 2 - Typical conventional Empire Abo Completion

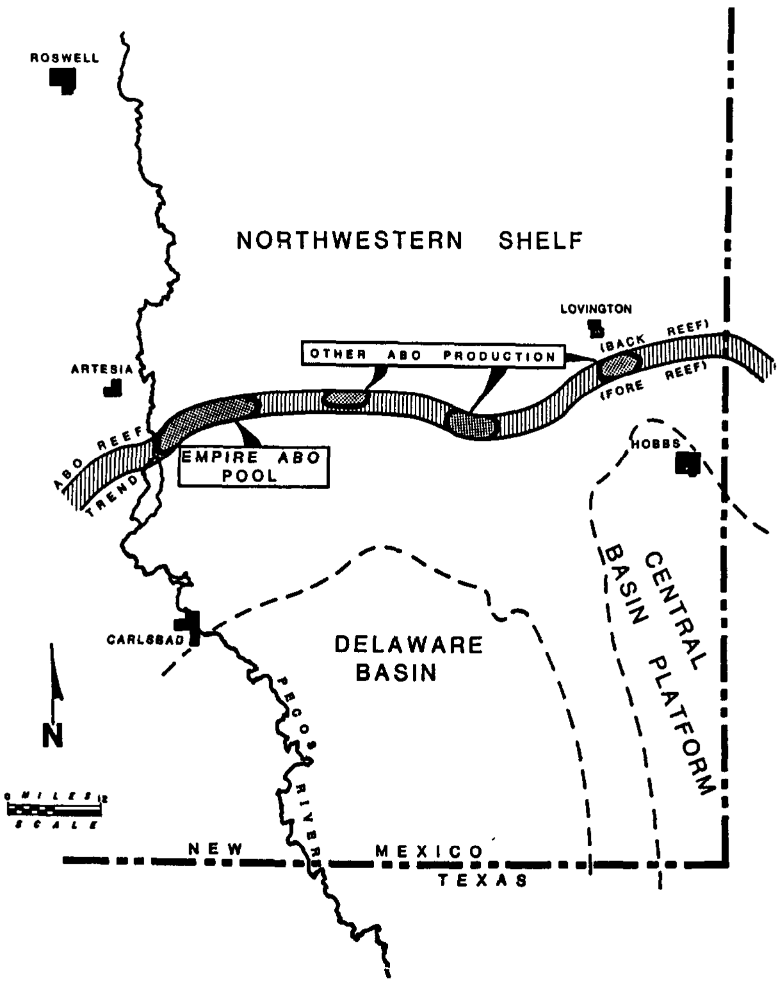

Figure 3 - Location of the Empire Abo Pool

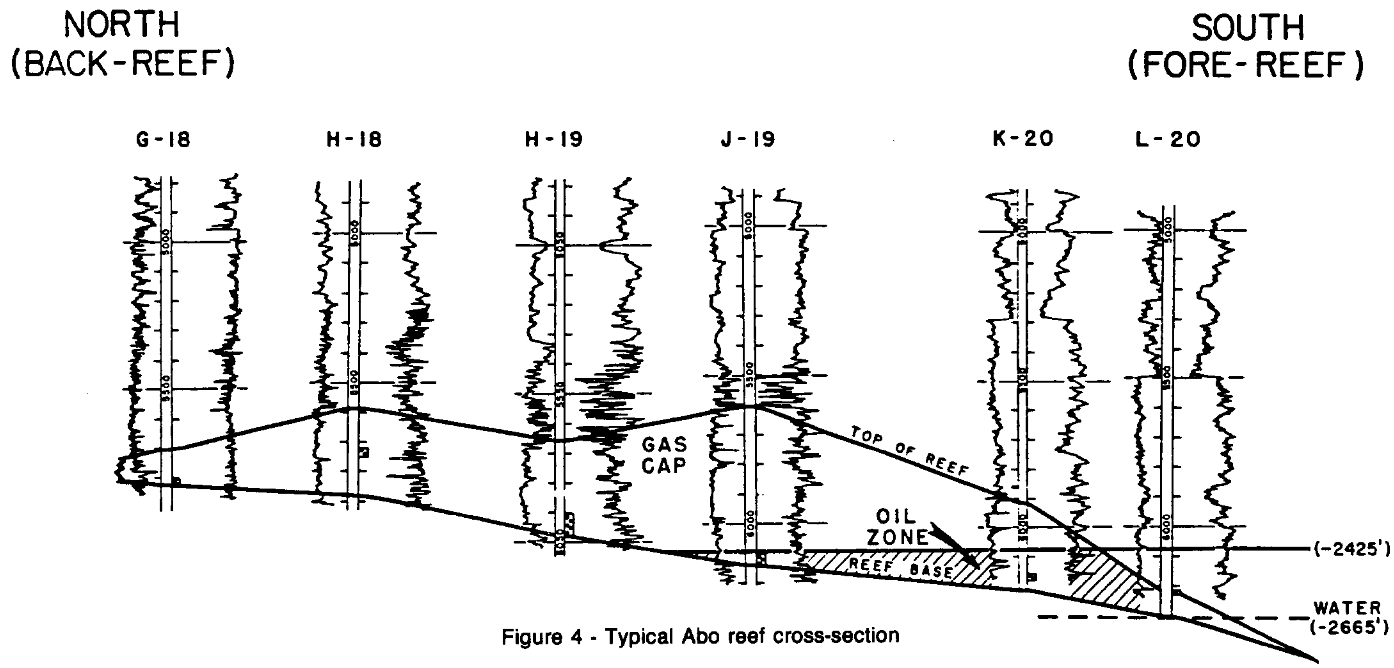

Figure 4 - Typical Abo reef cross-section

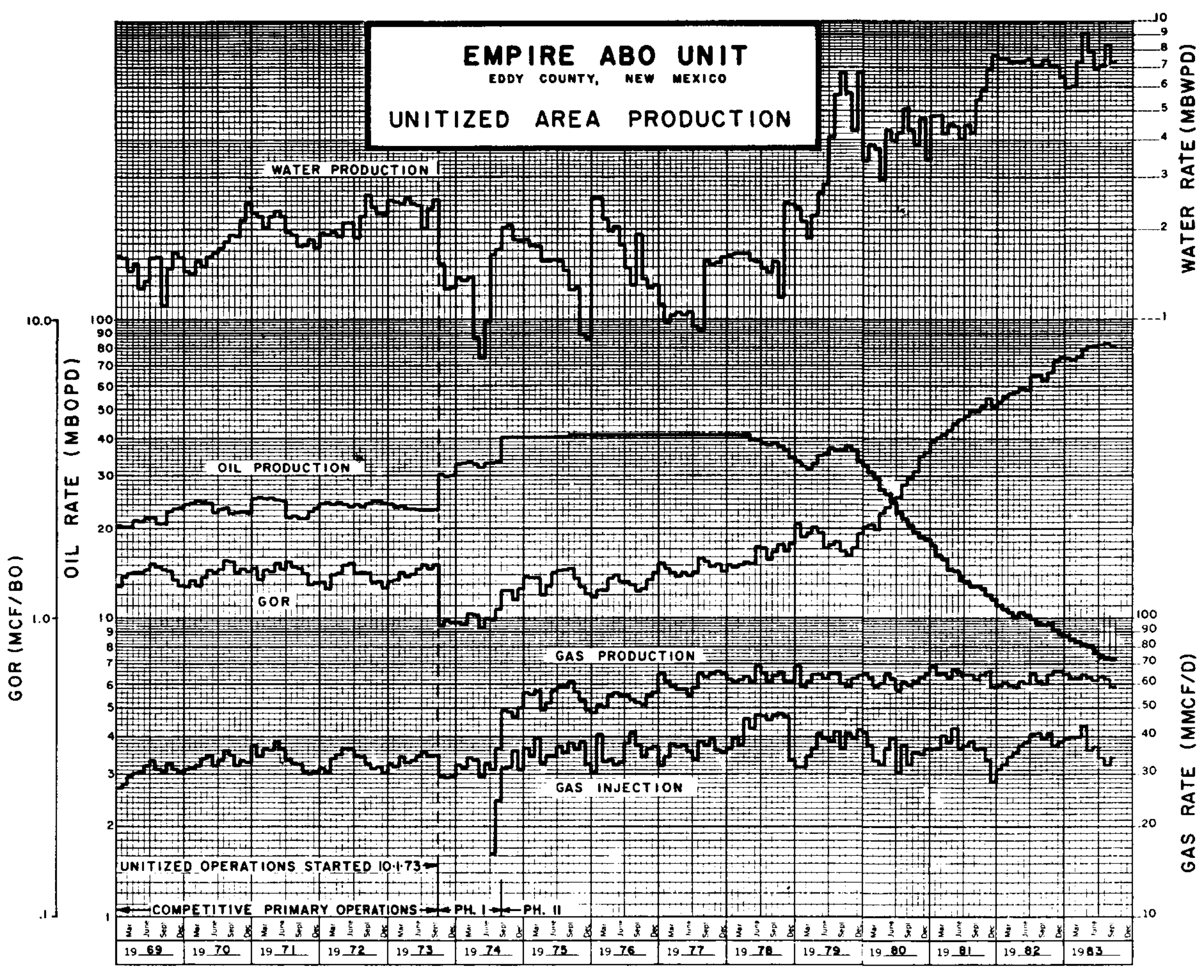

Figure 5 - Unitized area performance

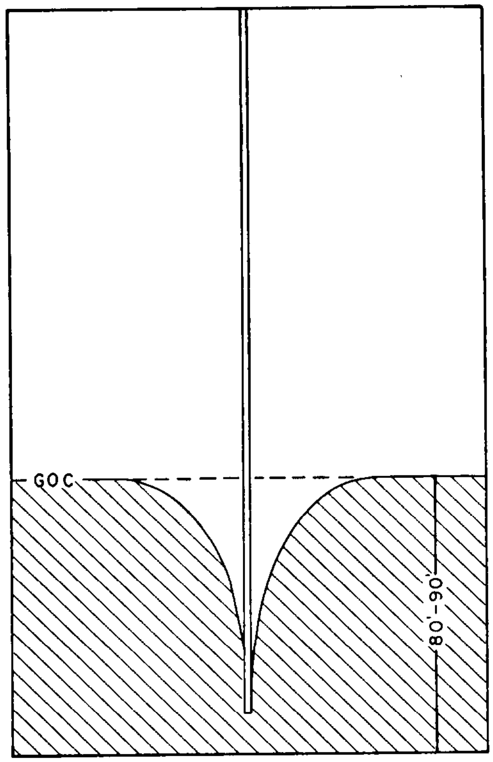

Figure 6 - Gas cone into conventional well

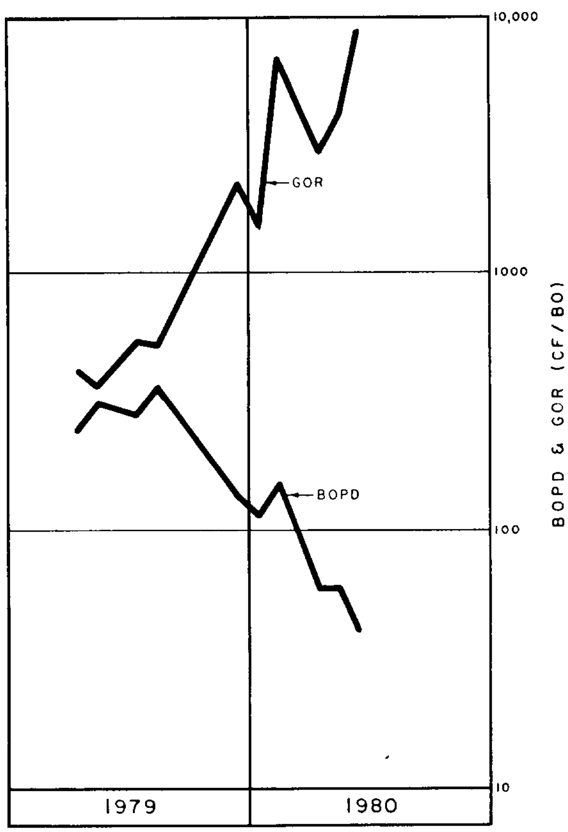

Figure 7 - Typical oil rate and GOR performance

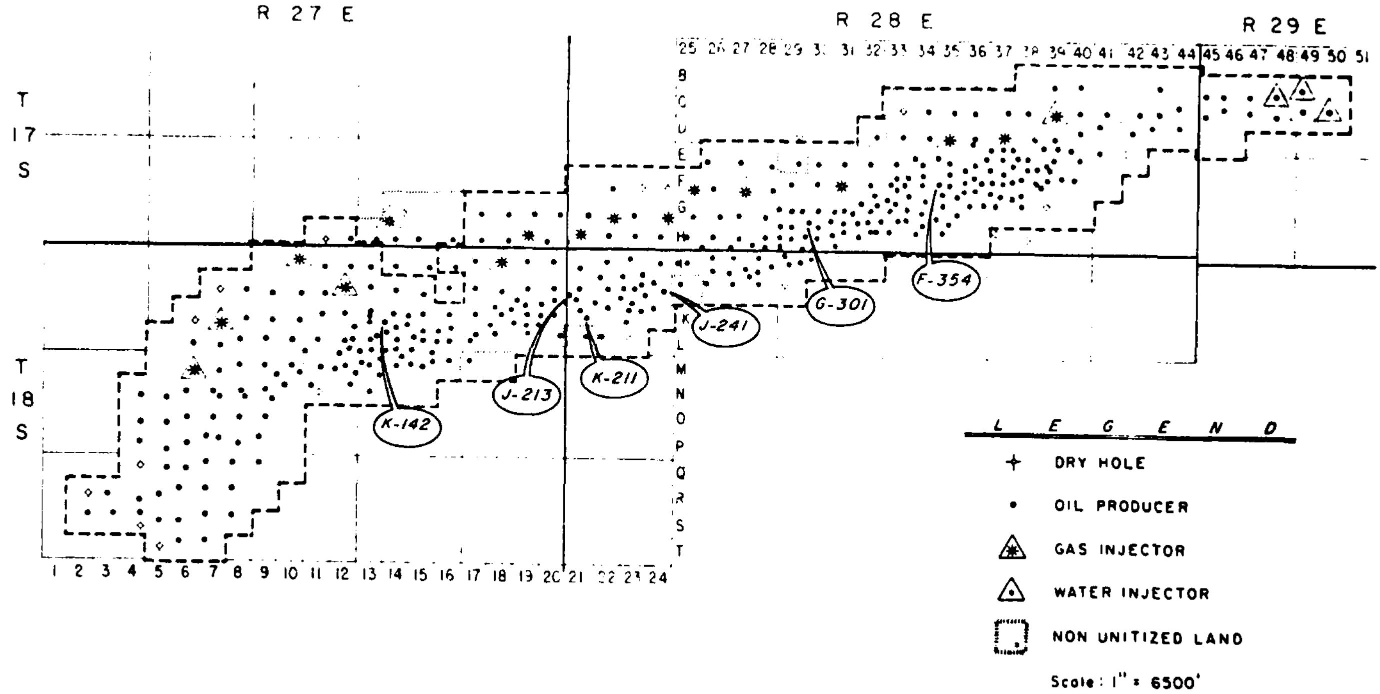

Figure 8 - Empire Abo unit map with drainhole locations

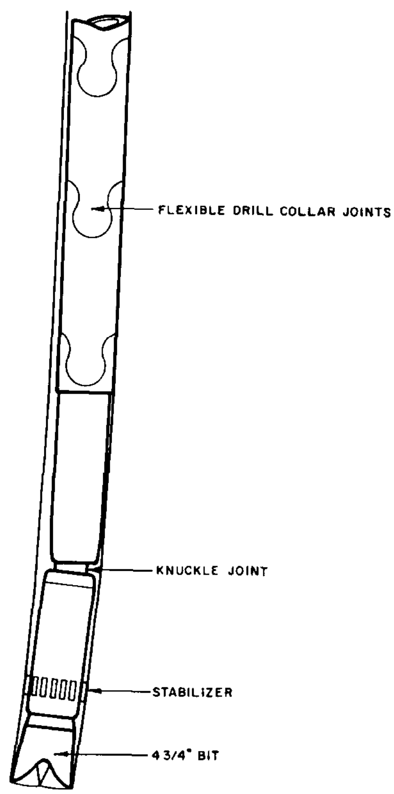

Figure 9 - Schematic of angle building bottom hole drilling assembly

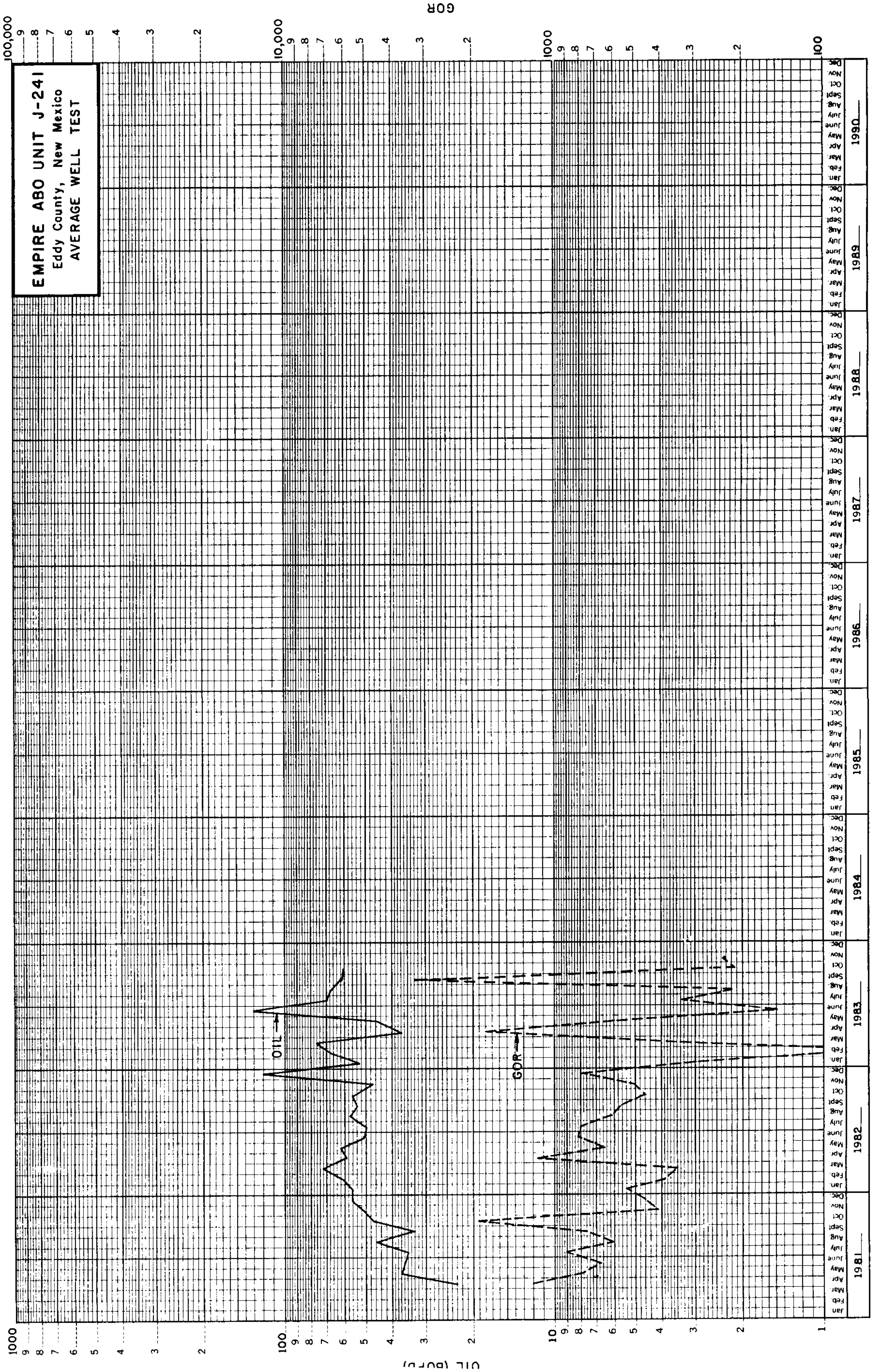

FIGURE 12. J-241 AVERAGE WELL TESTS

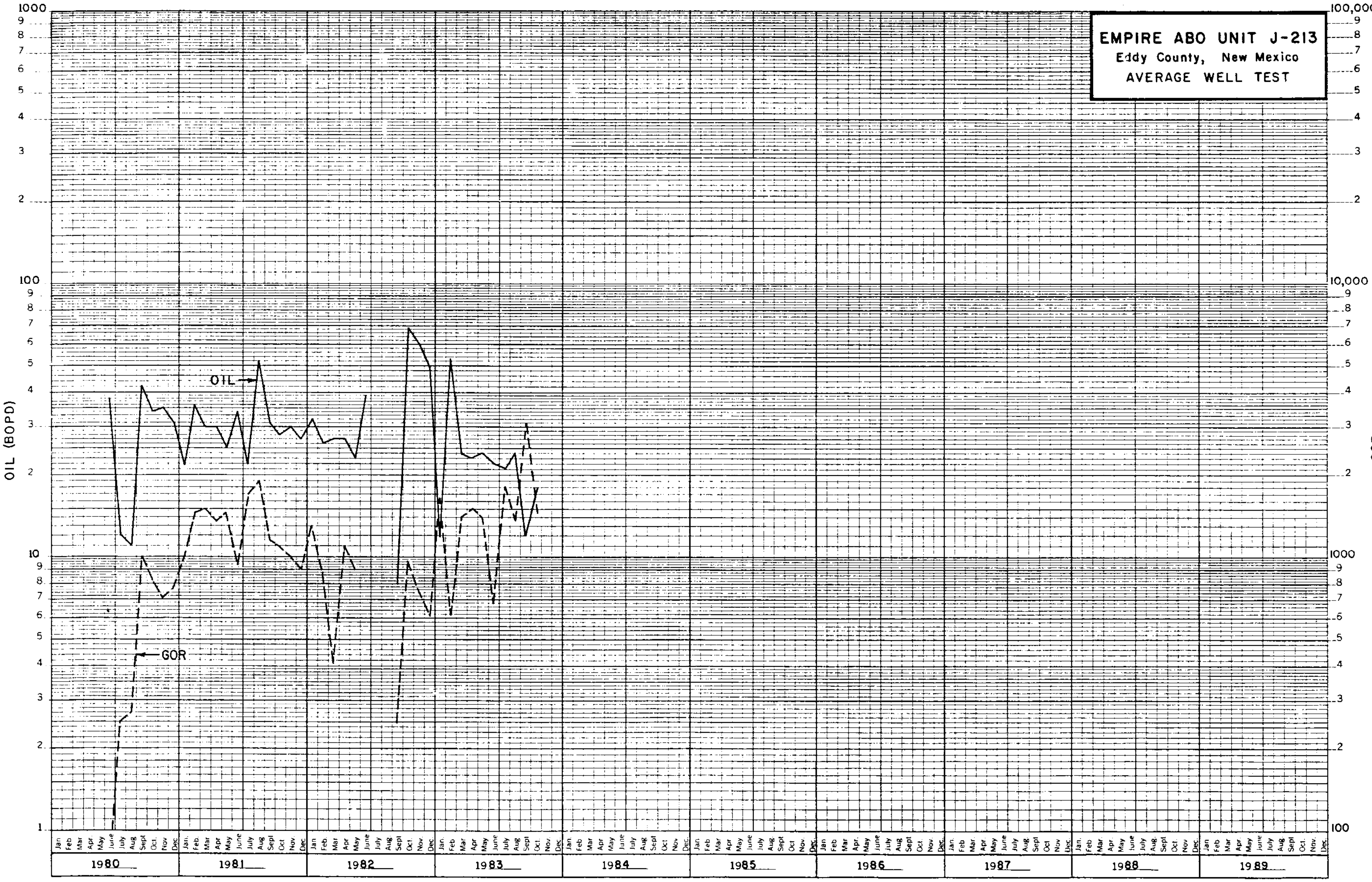

FIGURE 11. J-213 AVERAGE WELL TESTS

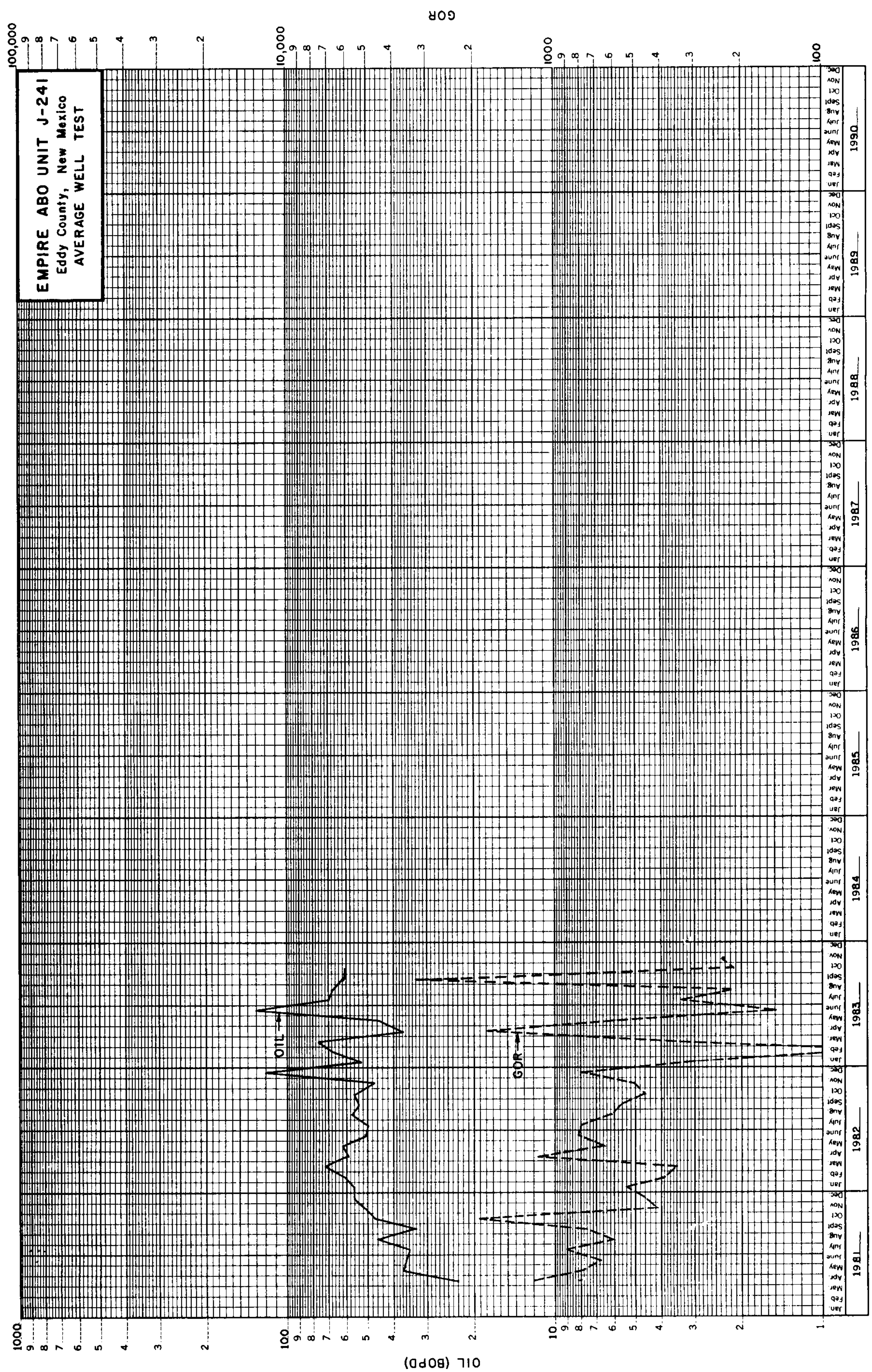

Figure 12 - J-241 average well tests

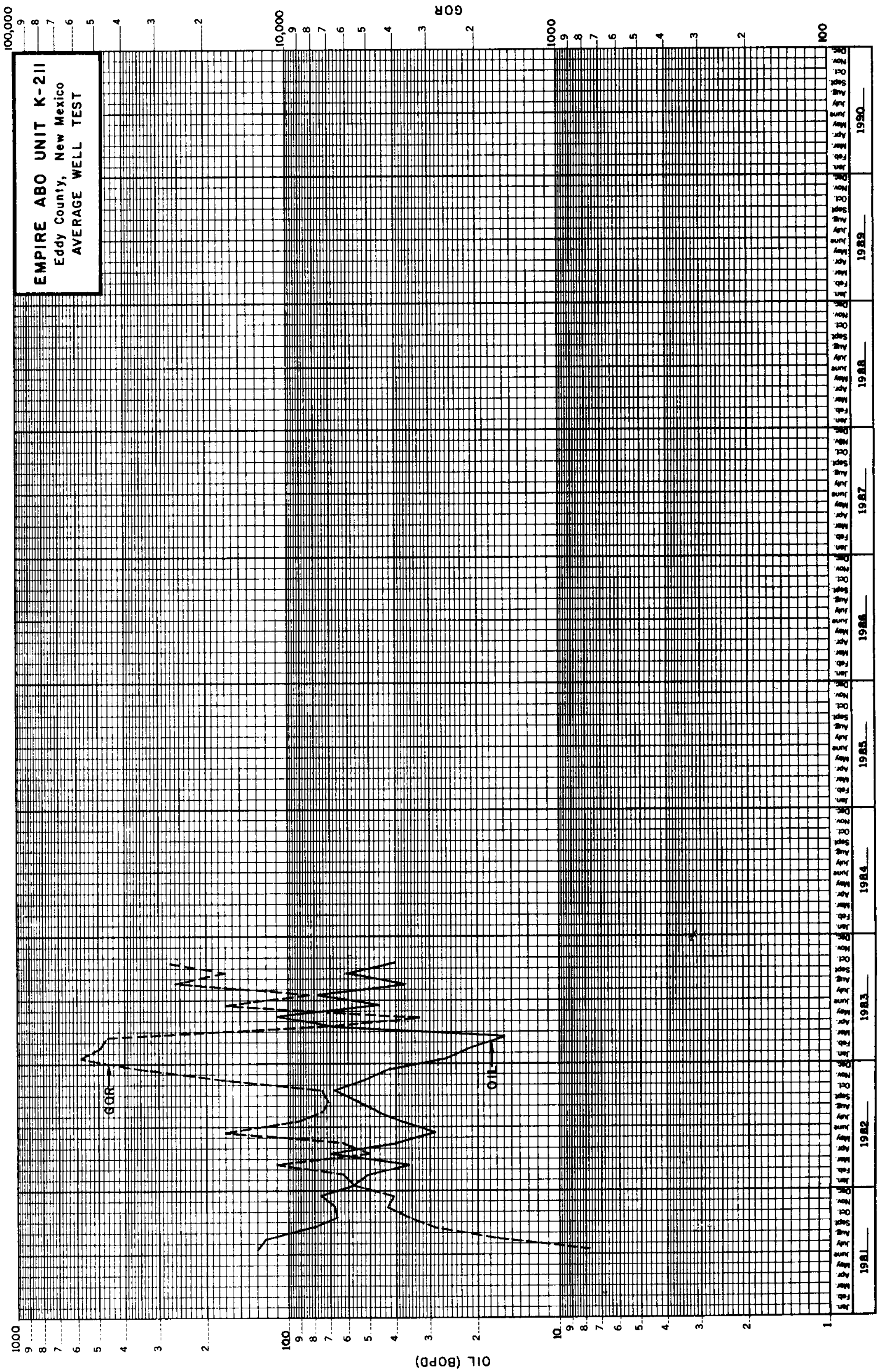

Figure 13 - K-211 average well tests

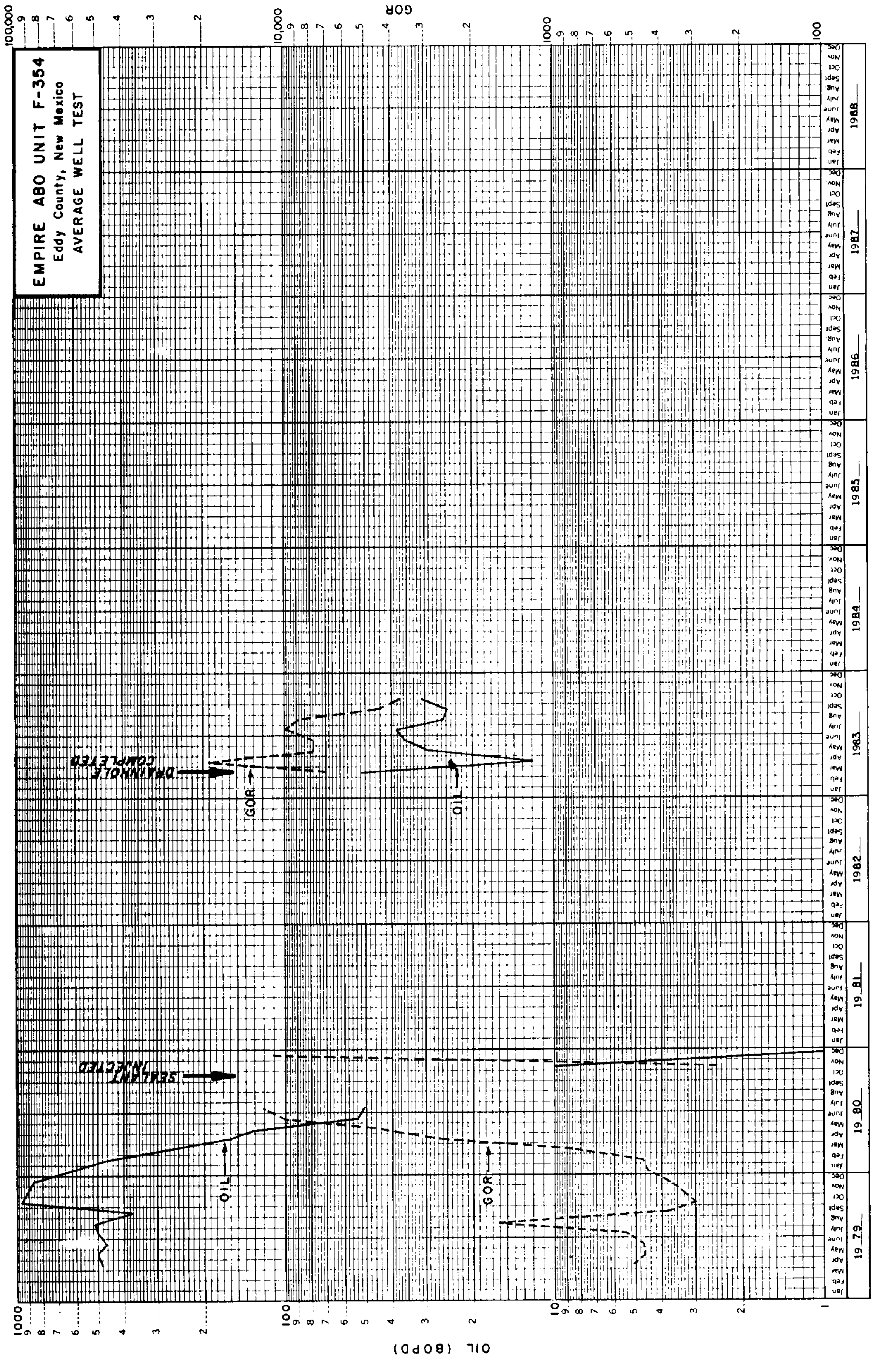

Figure 14 - F-354 average well tests

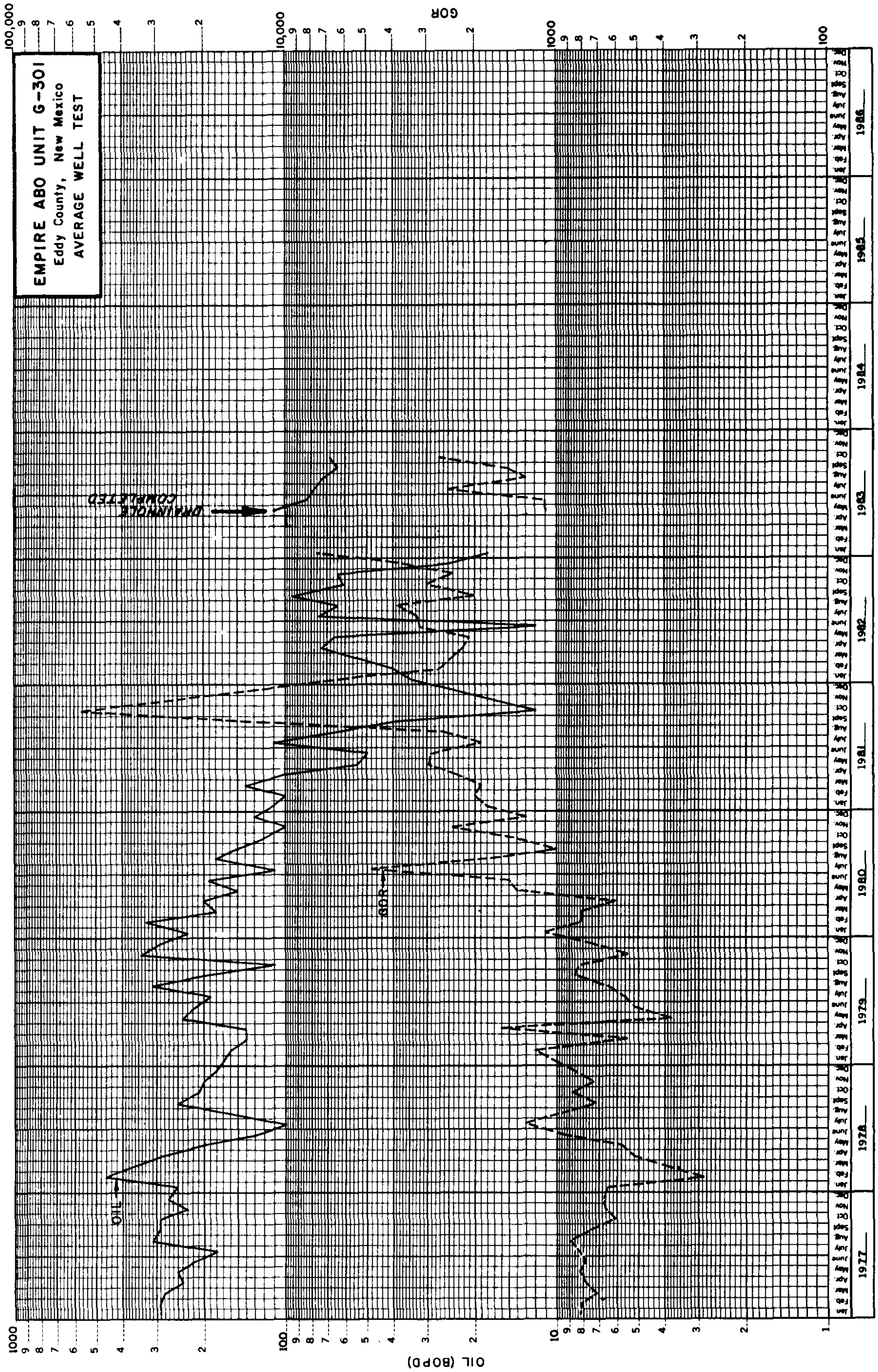

Figure 15 - G-301 average well tests.