Defining Oil and Water Entries In Producing Wells In The Permian Basin

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Subsurface analysis of fluid flow in producing oil wells is quite complex when compared to similar types of measurements in injection wells. Under injecting conditions, generally only one phase is present, usually water but also possibly hydrocarbons either in liquid or gaseous form. Under single-phase conditions it is relatively straightforward to measure the rate of fluid travel at any given depth, either by the use of an appropriate radioactive tracer or an electro-mechanical device such as the continuous spinner or packer flowmeter.

PRODUCING WELL FLOW CONDITIONS

In dealing with producing wells (under normal producing conditions), generally two phases (water and oil) are present; and in addition, free gas may also exist in the wellbore. Assume a system where the flow stream is 4-in. diameter or larger and rates where the water may range up to 2000 BPD and oil to 500 BPD. Under these conditions and in oil cut not to exceed 50 per cent of the gross fluid, flow conditions will probably be that of two distinct and separate fluids (water and oil), each having its own flow characteristics. In other words, the water will be present as the continuous phase from the intake of the flow string to the effective depth of the well, and any oil present will be as the dispersed phase. (It is likely that this condition will prevail where any water is being produced.) If free gas is present in the wellbore as a dispersed phase, it will complicate the quantitative identification of the other two phases and it is believed at this time there is no positive means of quantitatively identifying such gas. With this concept of separate continuous and dispersed phases, it follows that separate approaches are indicated to both qualitatively and quantitatively identify each phase.

APPROACH TO FLUID IDENTIFICATION

The electro-mechanical devices such as the continuous spinner or packer flowmeter have been successfully used to determine gross flow rates within appropriate limits for the particular tool. These tools do not have the capability of distinguishing between components in a multiphase flow system. The capacitance measurement is useful in identifying oil cuts in a water-oil system, but is evidently limited to water-oil ratios not exceeding approximately 3:1. Nuclear density tools have also been available for some time but do not appear to have been particularly successful in making subsurface quantitative measurements. Measuring small pressure changes in the well fluid column has also been reported in the literature as a means of identifying the presence of a dispersed phase or phases, but again the quantitative aspects do not appear to have been adequate to this time.

WATER IDENTIFICATION

Since in the vast majority, if not practically all instances for producing wells, water is the continuous phase, the use of radioactive water solution as a tracer makes the identification of this phase relatively straightforward, both qualitatively and also as to the rate of water movement. (It should be recognized at this point that high rates of oil and/or gas may significantly affect the movement of the continuous phase and consequently should be considered in the measurements being made with the RA tracer.)

Velocity Profile

Release of a small quantity of RA water tracer at any discreet depth in the well and noting its rate of movement over any desired vertical interval will provide the linear movement rate of the continuous phase over that interval.

Figure 1 illustrates this procedure whereby the time for upward-moving water to carry the RA tracer from its release point at the lower end of the logging tool by the detector is related to the distance "S" between the release and detection points to provide the corresponding rate. By knowing or assuming the confines of the flow stream, the linear rate can be translated into a corresponding volumetric rate. By taking a sufficient number of these readings at appropriate depths, a rate-depth profile is readily constructed which reveals the intervals contributing water to the wellbore and the respective quantities from each contributing interval. This utilizes the same approach used in profiling water injection wells with RA tracer, with the direction of water movement being opposite.

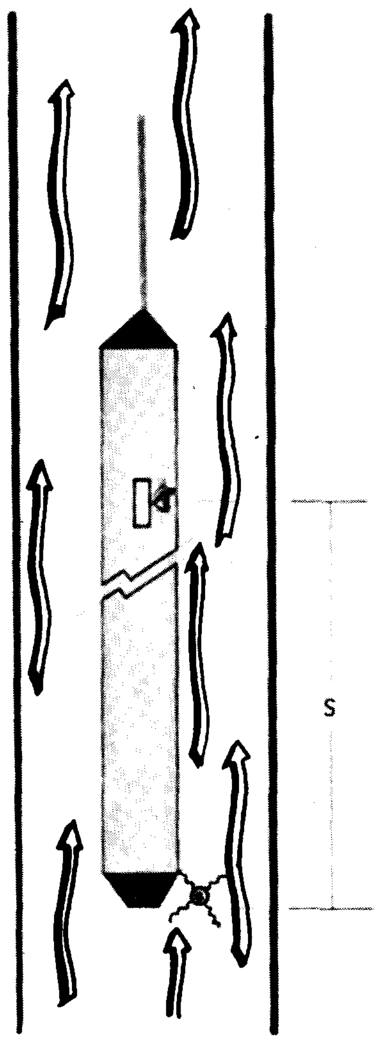

FIGURE 1

Water Velocity Determination

Conditioning-Dilution

A supplementary technique in identifyng these intervals is to "condition" the fluid column, or any portion thereof, with the RA water tracer and then to make a series of logging runs across the interval. Wherever water from the formation is entering the wellbore, it will dilute and displace the RA "conditioning" material. This procedure is generally very helpful in defining the limits of the entries and in particular the lower boundary; in many cases a rate can be calculated from interface movements.

The "conditioning-dilution" technique is illustrated idealized in Fig. 2. The left panel shows the condition in which RA material has been distributed throughout the column extending on either side of the two sets of perforations. From the top down, the first break in the RA trace denotes the change from the natural background to the RA "conditioning" material. The level of activity from the first break to the second break (top of top set of perforations) illustrates a decrease in activity due to the upward water movement. This is in comparison with the RA activity level in the static water column which is the condition portrayed below the top set of perforations.

The second or middle panel shows the first "logging" run following conditioning and points up the dilution and displacement effect that formation water entering the top set of perforations has on the RA material that has been introduced.

The right panel shows an additional logging run at some later time with the formation water having displaced the RA column an appreciable distance above the entry point. Comparing the two logging runs, it is obvious that a rate can be determined by noting the interface boundaries and the time intervals involved .

In general, the vertical intervals that can be successfully treated in the manner described will be up to several hundred feet in length and the time intervals between logging runs usually a few minutes up to fifteen to twenty minutes. These variables are governed by wellbore diameters and rates of production and are selected to suit each particular set of well conditions.

Temperature

As a routine part of the "water entry" survey, a temperature profile is recorded from above the bottom of the flow string to the effective depth of the well. This profile may be helpful in locating the boundaries of intervals that are

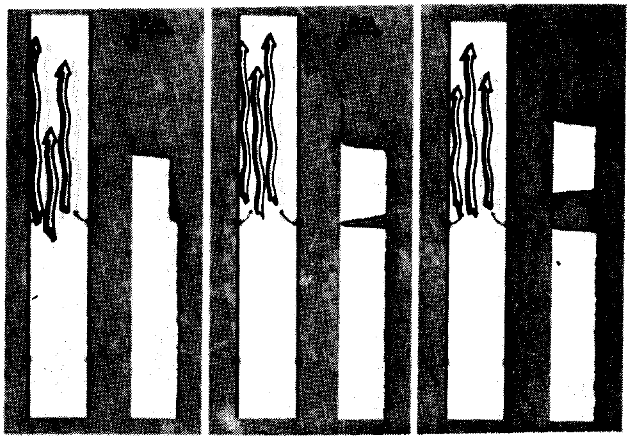

FIGURE 2

Conditioning-Dilution Method

contributing fluids by interpretation of the changes in the temperature gradient. Some interesting anomalies have been noted when the differential temperature has been recorded in conjunction with the water entry survey. At this time it is believed that little if any quantitative value has been derived from this particular application, but with more study and investigation, additional information may be gleaned from its use. An additional potential for the temperature data (including the differential presentation) is in its use after the dynamic-condition survey, when the well has been allowed to reach a static condition. Comparison of this data with the temperature data under dynamic conditions may reveal channeling behind casing and a "source" of fluid that may not be apparent from the dynamic survey. (In this, as well as any instance where a "static" temperature survey is to be relied on, it should be made certain that fluid conditions are indeed static when the survey is run.)

OIL IDENTIFICATION

Since any oil present in the fluid column below the flow string will be as the dispersed phase, the normal use of RA tracer to determine the presence and rate of oil is not applicable. An important feature of the two-phase flow system that should be recognized is that, unlike the continuous phase, the linear velocity of the dispersed phase is largely independent of its rate. This characteristic will certainly have limits affected by oil gravity and viscosity, flow rate of the oil, which flow regime is present (bubble, slug, etc.), the geometry of the flow system and probably other factors. Curtis[1] refers to the complications of multi-phase flow and Brown and Govier[2] have documented laboratory investigations in this field. To quote Brown and Govier, "In the region of bubble flow, which extends to an oil velocity of about 0.40 Ft/sec., the bubble velocity is relatively insensitive to the oil rate."

Recognizing the limitations of capacitance, density, and pressure measurements under downhole conditions, a different approach has been used with considerable success. This involves the concept of a chamber that will permit trapping the oil that is moving up the column at any given depth and electrically reading at the surface the quantity of oil present. Both the two-phase concept and the "oil locator" or "oil cut meter" approach are illustrated in Fig. 3. In this situation oil is entering the water column at both of the upper two sets of perforations and moving upward to the flow string intake. The cross sections at the left of the illustration depict the oil-water relation at the depths indicated. The sketches at the right show what the sampling device or trap "sees" at these same depths. Since the device is "sampling" the entire flow stream (assuming a uniform bore not exceeding the reach of the deflector at the bottom of the trap), the amount of oil trapped at any depth will be proportional to the oil volume or rate at that depth. Having the capability of opening and closing the trap and also reading the amount of oil collected at each station permits taking as many readings as required on a single trip in the well. The procedure at this time requires stationary measurements, so it is a matter of providing sufficient station readings to attain the desired profile.

WELL CONDITIONS

In order to obtain representative and meaningful fluid entry data, it is considered highly desirable to make the survey while the well is producing normally and under stable conditions. This may, on occasions, present problems since an additional requirement for a satisfactory survey is that the formation fluid have an upward path to the intake of the producing string, i.e., the bottom of the producing string be above all potential fluid producing intervals. In the case of low productivity wells, it may be that the well will not produce at its normal rate if the pump

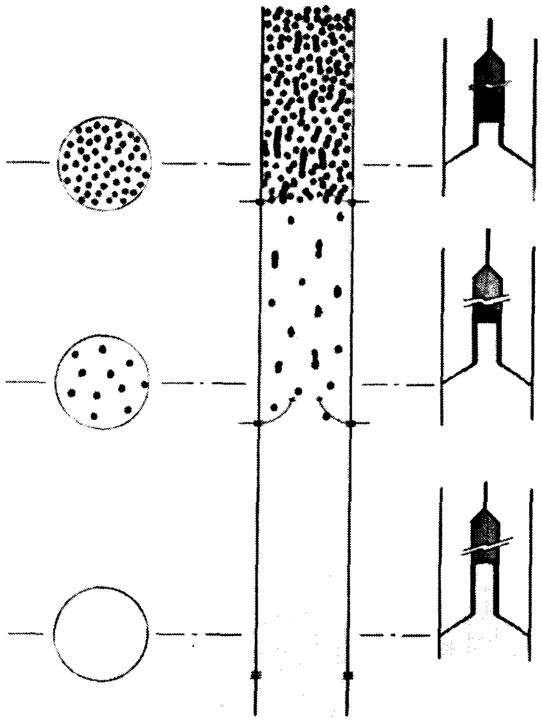

FIGURE 3

Oil Rate Determination

is located above all the zones open to production. If this condition prevails and two liquid phases are present in the wellbore, it should be realized that at best, only qualitative data will be obtained regarding fluid movement in the annular region between the tubing and the casing.

If the well is either flowing or gas lifting, the survey tools can be readily lubricated through the tubing and the only limitation is that there be no mechanical restrictions in the flow string that will hinder the passage of the survey tools. In the case of a rod pumped well, it has become routine to run the survey tools down the tubing-casing annulus and make the survey below the pump with the well producing normally. This procedure requires these conditions: (1) sufficient clearance between the tubing and casing to permit passage of the survey instruments; (2) a dual or offset head which provides an opening whereby the survey instruments can be inserted into the tubing-casing annulus; and (3) no restrictions in the annulus (tubing anchor, etc.).

If the producing string has been raised for a fluid entry survey, it is recommended that the well be allowed to produce under the new conditions for a sufficient time for the production to stabilize. Also, accurate production gauges are helpful in evaluating the results of the survey. (It should be recognized that the survey data is obtained over relatively short time intervals compared to some gauging procedures, so that if there is any substantial fluctuation in the well's production, there may well be a corresponding lack of agreement in the two sets of data.)

The question is frequently raised, "Is it safe to run instruments in the tubing-casing annulus?", or, "How often do you lose the survey tools when making annulus runs?" Experience is the only way to respond to this type of inquiry, since there is no way to predict what may happen in any particular well. In the vast majority of operations of this type, no difficulties are experienced in running and retrieving the survey instruments in annulus runs. When a problem occurs it is generally in retrieving the instruments from just below the casing flange as illustrated in Fig. 4. This shows the survey tool on one side of the tubing and the cable on the opposite side of the tubing. In this condition there is no way to retrieve the tool through the annulus opening by the usual means of reeling-in the cable. Fortunately it has been found that a special hand-operated "fishing" tool generally permits taking hold of the cable near the top of the fishing neck of the tool and withdrawing the survey tool through the annulus opening. The cable will still be looped around the tubing below the casing flange and it then requires cutting, pulling the free cable out of the annulus and reheading it. If this procedure is not successful in retrieving the survey tool, a service rig must be moved in and the flange raised to allow freeing the survey tool. From literally thousands of annulus surveys this company has run, the need for a service rig has occurred in less than five per cent of the operations.

SUBMERSIBLE PUMP ADAPTATION

With the increasing water volumes associated with waterflooding, submersible pumps

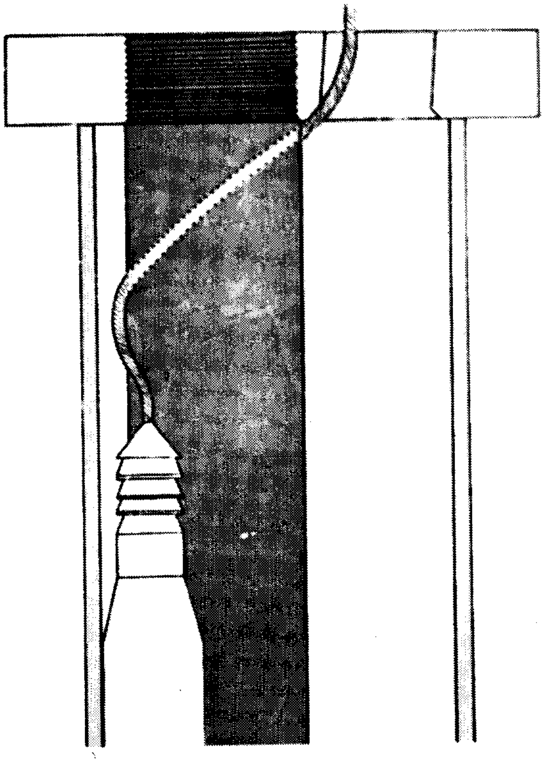

FIGURE 4

Survey Tool "Wrapped" In Annulus

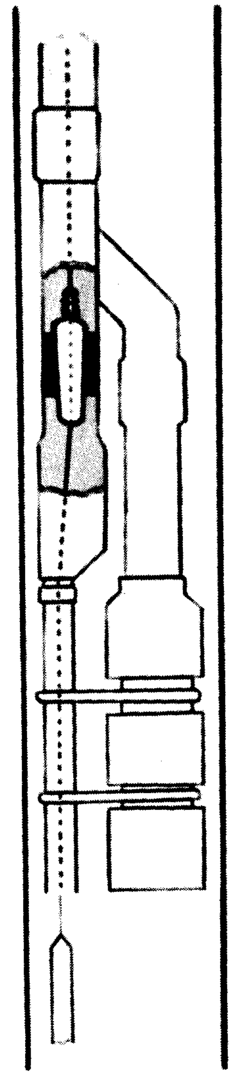

FIGURE 5

"Y" Tool Adaptation For Submersible Pump

have found increasing use to handle the larger fluid volumes in producing wells. The larger pump diameters and the power cable which parallels the tubing string introduce additional difficulties in attempting annulus surveys. Figure 5 illustrates an adaptation which has proven quite successful in permitting production surveys with a submersible pump. The "Y tool" assembly as it is called[3], offsets the pump, motor and associated components as shown to the right and provides a side string through which the survey instruments are run below the pump to the producing horizons. As illustrated, the cut-away section shows the "running plug" seated just below the junction of the Y with the logging cable running through it and the survey instruments extending below the assembly. When no survey is in progress, a solid "blanking plug" is placed in the position of the "running plug" in the illustration.

At the time of writing this paper, a similar approach is being tested for hydraulic pumping systems and it is anticipated that this will be as successful as that used with submersibles.

EXAMPLES

Figure 6 shows the results of an oil-water entry survey in an open-hole completion, requiring an annulus run between 2-3/8 in. tubing and 5-1/2 in. casing. The production figures for this well were 160 BWPD and 9 BOPD. A caliper run provides the parameter of bore diameter which is used in determining water rate and may also indicate favorable locations for oil readings if the hole size varies drastically. In this case the temperature gradient curve shows a noticeable change at the upper fluid entry and a characteristic change opposite the pump. (It is assumed that the tubing extending below the upper temperature anomaly is a stinger below the pump.) The temperature behavior in the lower part of the open-hole section suggests movement throughout the section, which if such existed, must have been very minor since it was not detected either with the RA water tracer or oil sampler. Radioactive velocity readings were taken every two feet where rate changes were encountered and revealed three distinct entries, the upper one of 60 BWPD and two lower ones of 50 BWPD each, as indicated. Oil readings were taken every four feet and indicated an upper entry of 5 BOPD and a lower entry of 4 BOPD.

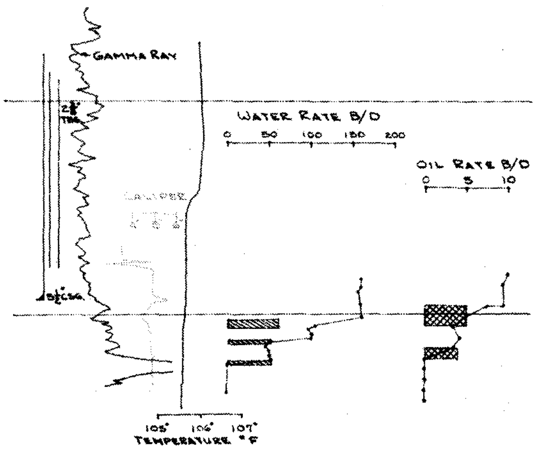

FIGURE 6

Oil-Water Entry Results

Figure 7 shows another open-hole completion (almost 250 ft below the shoe) and again with 2-3/8 in. tubing inside 5-1/2 in. casing. Production in this example was 65 BWPD and 15 BOPD. The temperature curve suggests fluid movement as deep as could be surveyed which was verified by both the RA velocity and dilution readings. Interpretation of the velocity and dilution data indicated water coming off bottom at approximately 50 BWPD and an upper entry of 25 BWPD, as shown. The oil profile reveals

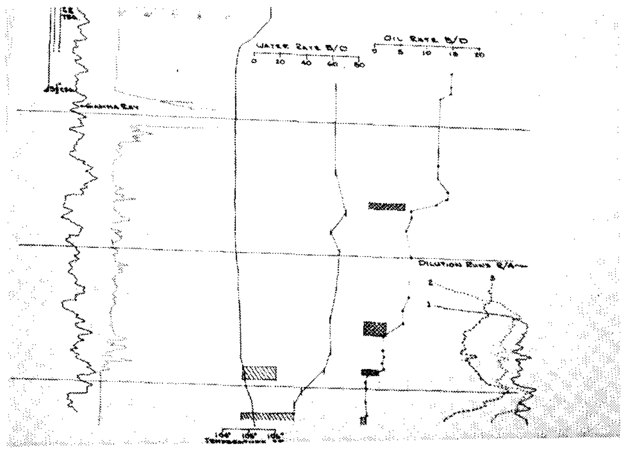

FIGURE 7

Oil-Water Entry Results

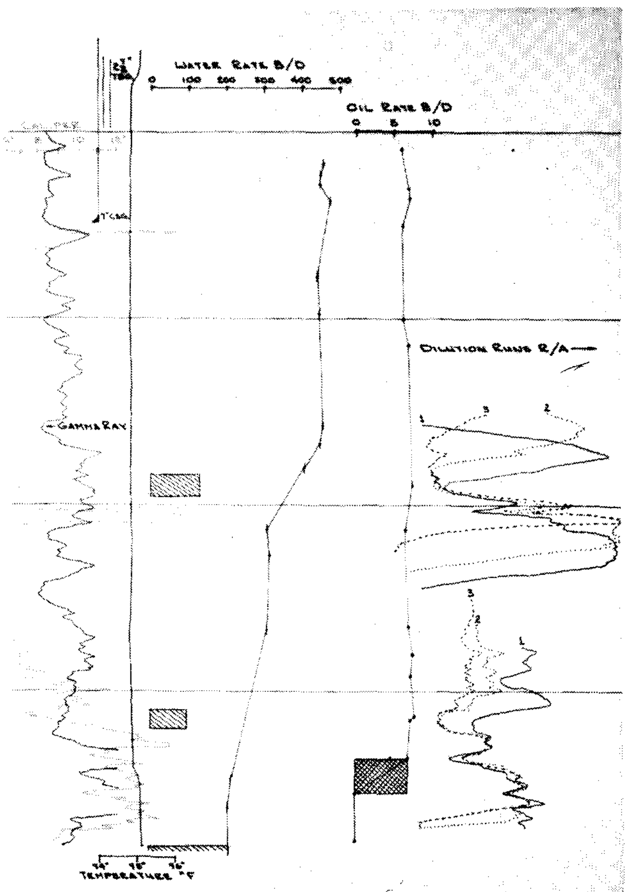

FIGURE 8

Oil-Water Entry Results

approximately 1 BOPD coming off bottom, and consecutively higher entries of 3, 4 and 7 BOPD as indicated.

Figure 8 illustrates an open-hole completion of approximately 350 feet with some severe changes in hole diameter. Production was given as 458 BWPD and 7 BOPD. The temperature profile suggests fluid movement off bottom, with the only other significant change being in the area noted as contributing oil. Radioactive velocity readings supplemented by two sets of conditioning-dilution runs, show water coming off bottom at a rate of 220 BWPD, an intermediate entry of 100 BWPD and an upper entry of 130 BWPD. The oil profile showed all of the oil coming in over one interval, as indicated.

Figure 9 illustrates the oil-water results from a perforated 5-1/2 in. casing completion with 2-3/8 in. tubing with production of 119 BWPD and 10 BOPD. The combination of RA velocity and conditioning-dilution data indicates water entries from the bottom up of 10, 45, 28, and 41 BWPD, as shown. This provides a particularly distinct portrayal of how well-defined water entries can appear from the condition-dilution technique. All of the oil production in this case was found to be entering from one interval, as shown.

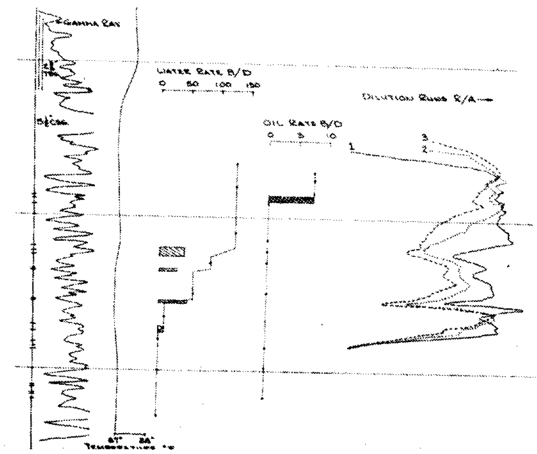

FIGURE 9

Oil-Water Entry Results

CONCLUSIONS

Defining oil and water entries separately and quantitatively in a producing well has become a routine procedure within the physical limits of the well completion. Annulus runs are successfully made between 2-3/8 in. upset tubing in 5-1/2 in casing or 2-7/8 in. upset tubing in 6-5/8 in. or larger casing. This type of information should be of value in evaluating overall reservoir performance or in planning and carrying out effective remedial action in an isolated well.

REFERENCES

1. Curtis, M. R.: Flow Analysis in Producing Wells. SPE-1908, Houston, Texas, October 1-4, 1967.
2. Brown, R. A. S. and Govier, G. W.: High-Speed Photography in the Study of Two-Phase Flow. The Canadian Journal of Chemical Engineering, August 1961.
3. Yancey, I. R. and Khamis, A. G.: Submersible Pumping Operations. SPE 2737, San Francisco, California, November 6, 7, 1969.
4. Schaller, Herman E.: Subsurface Flow Measurements in Producing Wells. SPWLA Ninth Annual Logging Symposium, June 23-26, 1968.