Well Log Applications and Interpretation in a Brine Field

James M. Bird
Birdwell Division of
Seismograph Service Corp.
Tulsa, Oklahoma

The purpose of this paper is to discuss the application of wire line services that have evolved as servants of the oil and gas industry to some of the subsurface problems generated by the solution mining of salt. This transplanting of techniques can be beneficial to both parties.

In the last 35 years, the wire line industry has proliferated its services to the extent that it is now difficult to sensibly organize them. However, all have one thing in common. They involve the lowering of electromechanical devices into holes in the earth on the end of electrical cables. I further choose to divide all these services into two categories. Historically, the first and still the most significant is the category that I will designate "Data Gathering." The second category I designate "Action Producing."

In the first category, data from the bottom of the hole is gathered for one of two reasons. The data gathered is used to either evaluate the type and physical characteristics of the formations uncovered by the bit, or the information is used to aid in the drilling or completion of the well.

In the Action Producing group are many different services. The most common are perforating, setting of plugs and packers, etc. Due to the pressure of time, these services will not be discussed in this paper. I am limiting myself to the data gathering group. In this group, I intend to limit the discussion almost entirely to those services that our personnel have had experience with in the salt mining field. I will discuss, briefly, the theory of operation of these particular services. This will be followed by examples of their use and behavior in salt wells.

In the first group, the formation evaluation group, measurements of the formation are made in either empty or fluid-filled, cased or uncased holes.

The Gamma Ray-Neutron Stack, see Fig. 1, is most used because of its ability to take measurements in either open or cased, empty or fluid-filled holes. The Gamma Ray tool utilizes either Geiger-Mueller or a Scintillation detector. The length of detector ranges from four to 12 inches. It is considered to be eccentralized in the well bore. The detector measures the number of gamma ray emissions coming mostly from three elements; potassium, thorium or uranium. Because these elements are usually found in shale, the gamma ray log may be used quantitatively to determine shale content of the formation being evaluated. In this way it becomes the primary log for determining the lithology of a well drilled for the purpose of mining salt.

The Neutron tool utilizes either a Geiger-Mueller or Scintillation detector. The length of the detector ranges from four to six inches. The spacing, distance between source and detector, will depend on the depth of investigation desired, the diameter of the well bore and the type of fluid in the well. It usually ranges from 16 to 32 inches. Two common sources in use today are Plutonium Beryllium and Radium Beryllium. The detector can be of the type that is sensitive to either gamma rays or neutrons. Like the Gamma Ray tool, it is considered to be eccentralized. Quantitatively, the Neutron Log measures hydrogen content. Briefly, this is accomplished by the fast neutrons being slowed to thermal condition at a rate proportional to the hydrogen present in the range of spacing of source to detector. When the neutrons become thermal, they are captured by formation which in turn emits gamma rays.

Figure 2 depicts a Guard tool which is a focused current device. It is used primarily in either salt water or salt mud-filled well bores. The guard electrodes are mechanically and electrically connected and extend 64 inches (more than ten times the measuring electrode spacing) above and below the measuring electrode. Their function is to maintain an equal potential in the well bore. The measuring electrode is usually five and one half inches long. It makes an excellent tool for thin bed definition. It is the only resistivity device with the capability of measuring the resistivity of the wall while operating in the immediate environment of a very low resistivity liquid-filled bore hole. Salt water is such a low resistivity environment.

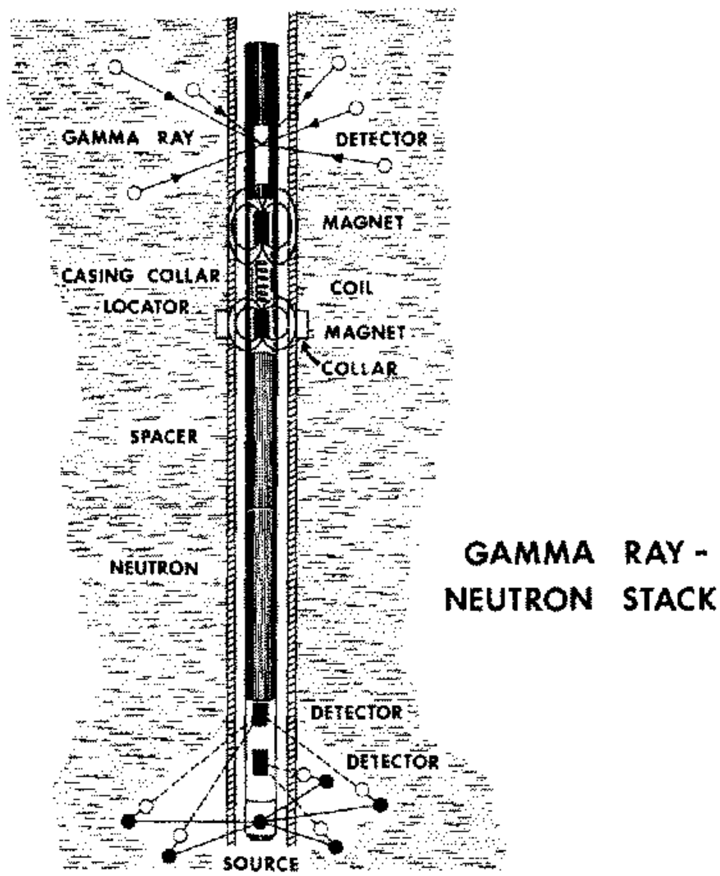

Figure 1

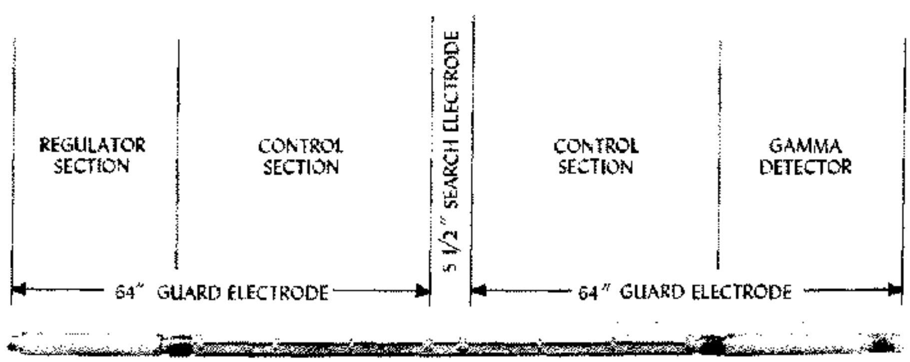

Figure 2

The Formation Density Tool (Fig. 3) is a nuclear measuring device. It utilizes a gamma ray source and gamma ray detector. The source and detector are shielded from each other so that few

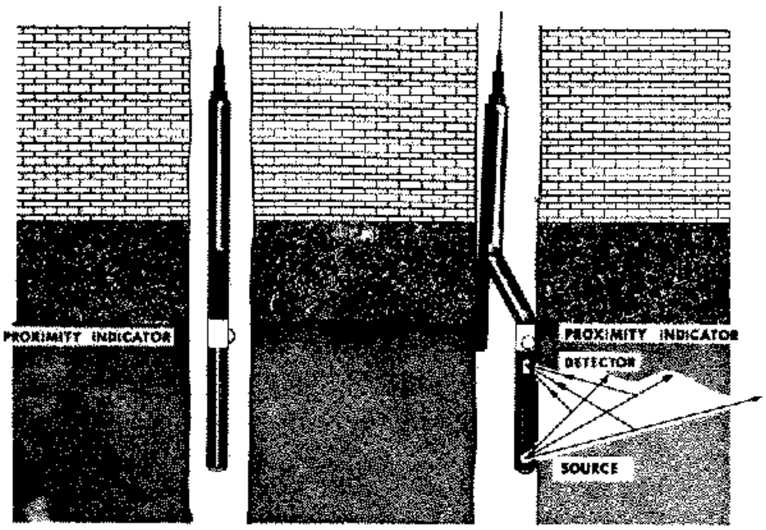

Figure 3. Formation Density Tool.

gamma rays can migrate through the tool itself, from source to detector. The tool goes into the hole as a straight tool and may be put into a logging position by electronic controls at the surface. To eliminate undesired borehole effects, the tool must be urged against the wall of the well bore. In order to determine any standoff between the working face of the tool and the wall, a proximity indicator is incorporated. The double elbowed arrangement makes it possible for the lower part to remain in contact with the wall in holes up to ten inches in diameter, and in washout zones more than three feet thick. The tool simultaneously records a proximity index and bulk density in grams per cubic centimeter.

The 3-D Velocity Tool depicted in Fig. 4 is an acoustic measuring device utilizing transmitting and receiving transducers. The spacing between transmitter and receiver can be from three to 30 feet. The spacing being chosen on the basis of the type of data that one hopes to measure. The tool is always centralized and must utilize the fluid in the well bore to transmit the signal to the formation. It is necessary to acoustically isolate the transmitter and receiver. For a more detailed explanation of the 3-D Velocity Log, I wish to refer you to the paper, "The Determination of the In-Situ Elastic Properties of Rock Salt with a 3-Dimensional Velocity Log" presented by D.M. Christensen at this symposium.

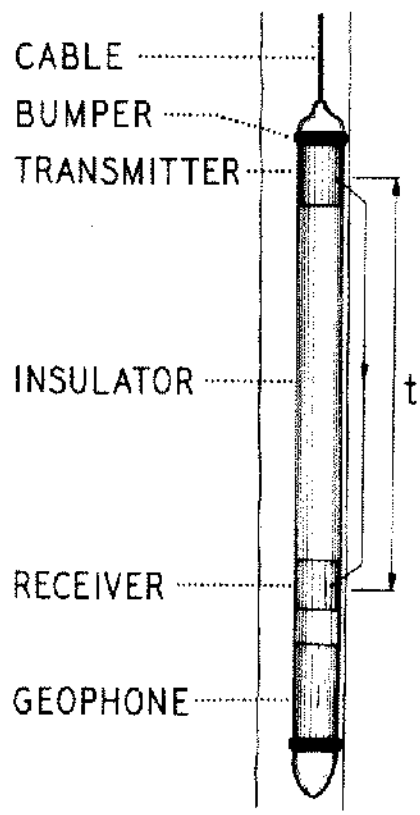

Figure 4. 3-D Velocity Tool.

Some of the outstanding features of the logs presented in Fig. 5 are as follows: The formation tops may be easily correlated. There are few shale inclusions in the salt section as evidenced by the low gamma radiation. An extremely low hydrogen content exists in the salt sections. This property is shown by the neutron log. Higher resistivities prevail in the salt sections than in the limes and shales. The bulk density of the salts are approximately 2.16 grams per

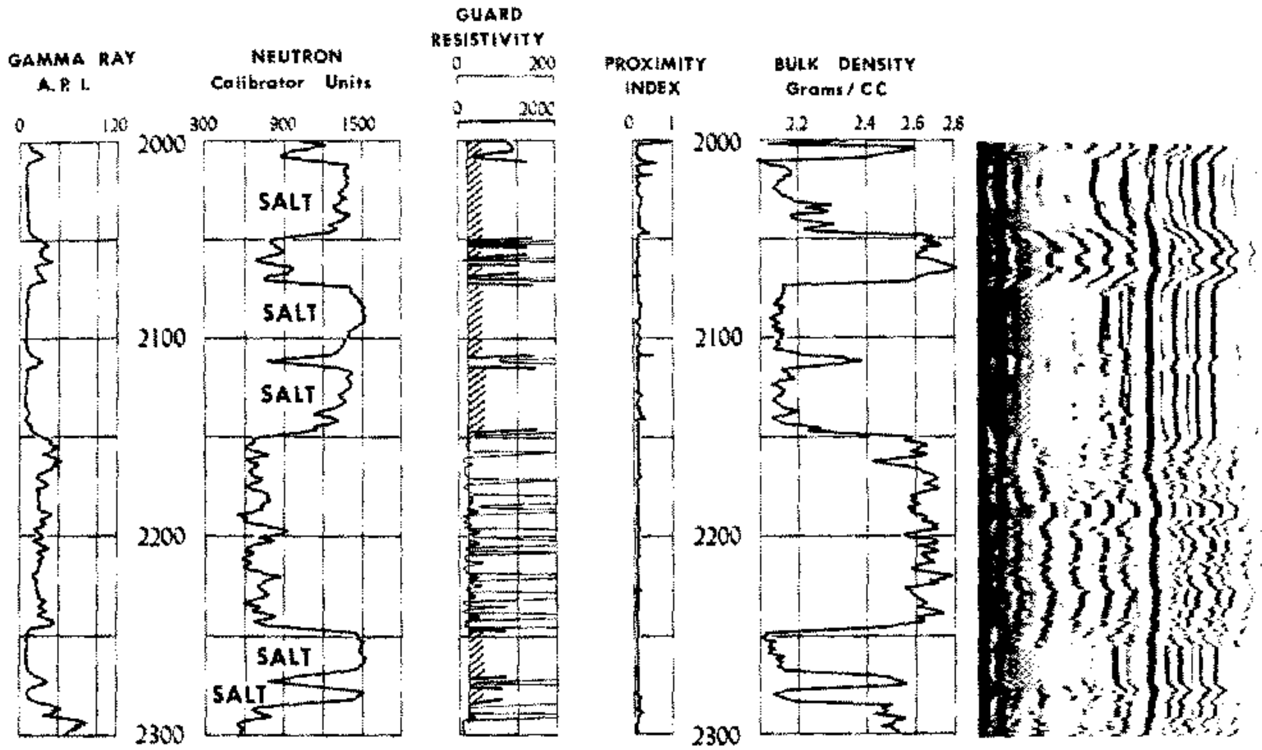

Figure 5. 3-D Velocity Log

cubic centimeter which is anomalously low for formations with high resistivity. The 3-D Veloci Log indicates very homogenous beds of 15, 000 ft. /sec. velocity. The combination of low shale content, low hydrogen, high resistivity, low density and high velocity is a logging fingerprint fo salt.

Let us turn our attention to the use of logging tools whose purpose is to gather data to aid the completion and operating of wells in salt fields.

One of these services is the Caliper which is designed to enter the well bore with arms closed. The Caliper is electronically controlled from the surface so that the arms may be open as shown in Fig. 6. With control at the surface, it is possible to open the arms and record a lo and then return to the bottom of the well bore to make a repeat run. The desired sensitivity ma be gained by changing the length of the arms, which determine the maximum diameter that may recorded. Each of the three arms act independently, thus, the diameter recorded is that of a circle described by the tips of the three arms. The spring tension on the arms tend to hold the tool centered but this may not necessarily be the condition at all times when recording. One of the latest features is the addition of surface equipment designed to compute the volume of the borehole to an accuracy of $\pm 5\%$.

Figure 7 depicts the use of well completion logs. Curve # 1 indicates the diameter of the well bore at first completion date. Curve # 2 indicates where a mechanical notcher was used to increase the well bore diameter at approximately 2, 440 and 2, 460 feet. The purpose of the not was to induce a fracture in the lower salt in an attempt to produce this section first.

Curve # 3 represents the use made of a magnetic Casing Collar Locator to determine the depth of tubing collars and inflatable packer. It was desired to place the two packers so they would straddle the lower notch.

Curve # 4 shows the diameter after pumping into the well for a period of 45 days. Note th sloughing of siltstone from 2, 340 to 2, 350 feet.

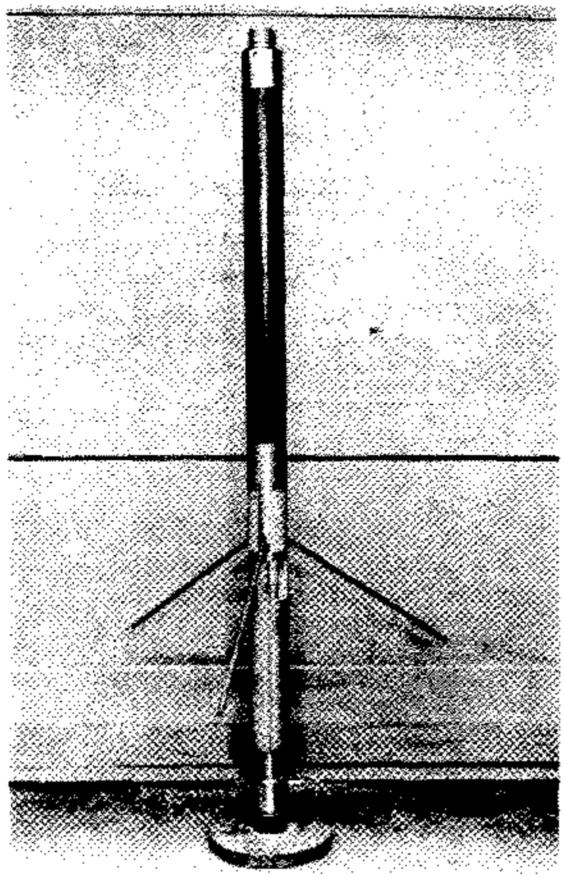

Figure 6. Caliper.

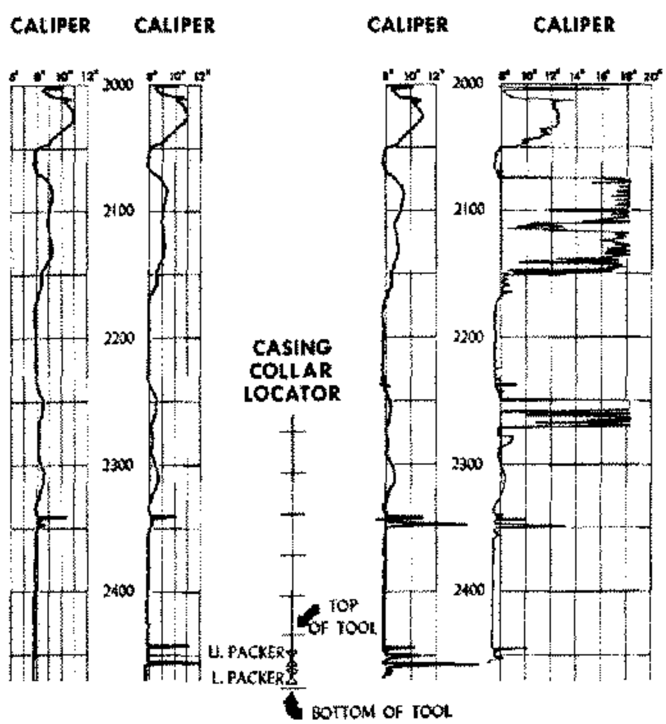

Figure 7

Curve # 5 represents the diameter of well bore after 45 days of water injection. Note the leaching action that has caused increased hole diameter in the upper four salt sections. This was an undesired result as it was hoped to force leaching in the bottommost salt section first.

When it is impractical to pull a liner to determine where solution action is taking place, a Neutron Log may be run in lieu of pulling the liner and running a Caliper. In Fig. 8 Curve # 1 is a Gamma Ray Log and indicates lithology. Curve # 2 is a Neutron Log that was made with hole diameters as indicated by the Caliper (Curve # 3). After approximately five months injection, another Gamma Ray-Neutron Log (Curves # 4 and # 5) was run to determine which salt zones were being affected. The changes in zones from 2, 062 to 2, 100 feet and 2, 106 to 2, 138 feet is apparent Some change had been made in the zone from 2, 002 to 2, 035 feet. Note the eight-foot zone from 2, 030 to 2, 038 feet. At the time the liner was pulled, a long-armed Caliper was recorded to confirm washed out zones indicated by the Neutron Log.

A Temperature tool and log may be classified as a formation evaluation as well as a well completion tool. The Temperature tool depicted in Fig. 9 displays a gamma ray tool to which the temperature module is attached. The temperature sensing device must be so positioned that the temperature of the material supporting it will not affect the recorded temperature. The pictured tool utilized a thermistor as the temperature sensing device. It contains an element whose resist ance changes appreciably with small changes in temperature. A thermistor has a very short time constant in water and acceptable time constants in gas and air.

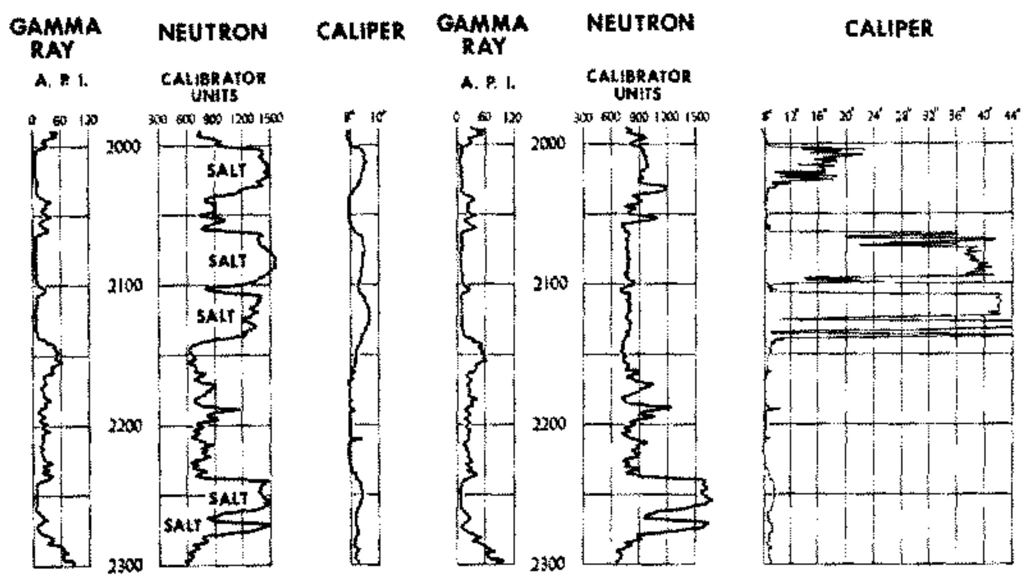

Figure 8

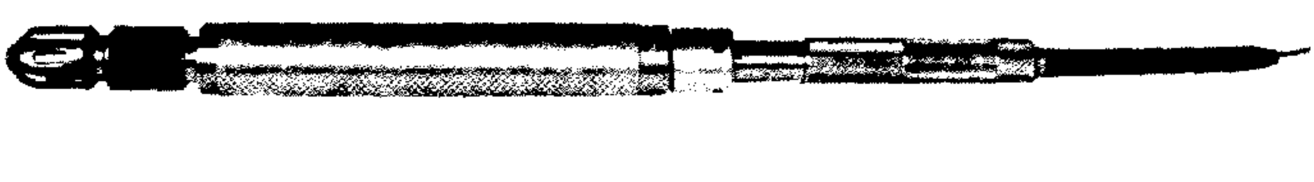

Figure 9, Temperature Tool.

Figure 10 indicates what can be determined by a temperature log as a result of an endothermic process such as occurs when sodium chloride is dissolved in water. The absorption of heat from the injection water results in the anomalies shown in this slide.

Curve # 1 and # 2 is a Gamma Ray-Neutron Log run on an injection well. Curve # 3 is a Temperature Log run on the well the same day. Note the Neutron Log indicating a cavity at 2, 220 to 2, 240 feet, and another cavity from 2, 265 to 2, 330 feet. The Neutron Log does not show solution activity too conclusive, but the Temperature Log indicates activity down to 2, 480 feet.

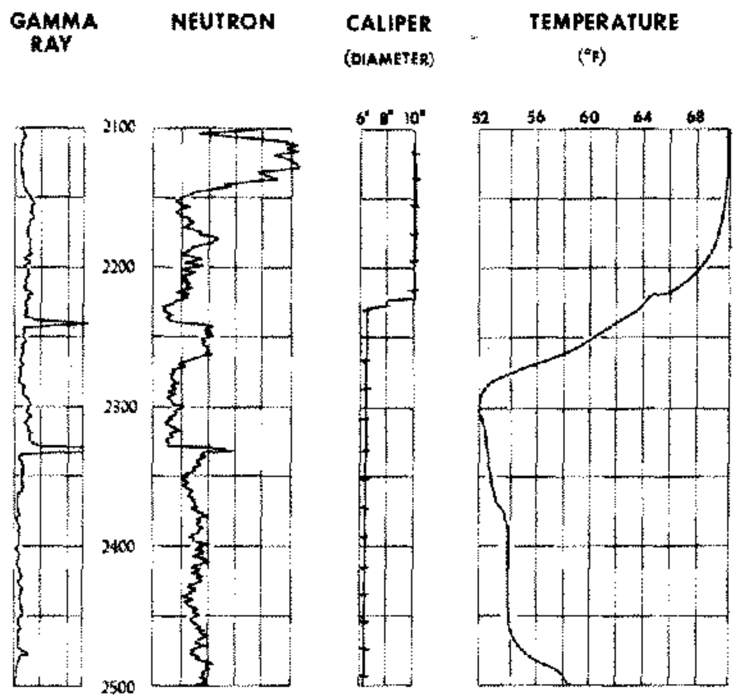

Figure 10

Curve # 1 and # 2 of Fig. 11 is a Gamma Ray-Neutron Log run on the well at completion date. The Temperature logs were run under the following conditions: Curve # 1 was recorded after the well had been inactive for approximately 30 days. The log indicates that solution activity had taken place from 1, 990 to 2, 140 feet. Curve # 2 was recorded after one hour of injection. The well was flowing back at the rate of 20 gallons per minute. Solution activity is apparent at the base of the pipe set at 1, 990 feet. Following the recording of Curve # 2, the well was injected into for nine days. The injection was stopped and the well allowed to reach a static condition. Curve # 3 represents the Temperature Log indicating where the endothermic process took place in the well.

Figure 12 indicates the temperatures and calipers recorded on an active injection and producing well. Curve # 1, a Caliper, indicates the top of the cavity to be at 2, 338 feet. This is precisely the depth the Temperature, Curve # 2, indicates solution activity is taking place in the injection well. Curve # 3 shows a cavity existing at 2, 368 feet in the active producing well. Curve # 4, a Temperature Log, indicates no solution activity in this well. It can, therefore, be assumed all solution activity is taking place in the injection well.

An example of how a magnetic casing collar locator and a Caliper Log may be used to determine a poor pipe condition existing in a well is presented in Fig. 13. Curve # 1 is a Gamma Ray Log of the well. Curve # 2 is the recorded casing collar locator. An examination of the curve indicates unexpected metal changes at 2, 025 and 2, 118 feet. Curve # 3 is a Neutron Log of the problem well. Note the washed out salt section from 1, 985 to 2, 026 feet. Also, the salt section immediately above and below the depth of 2, 118 feet. Curve # 4 is a Caliper Log of the

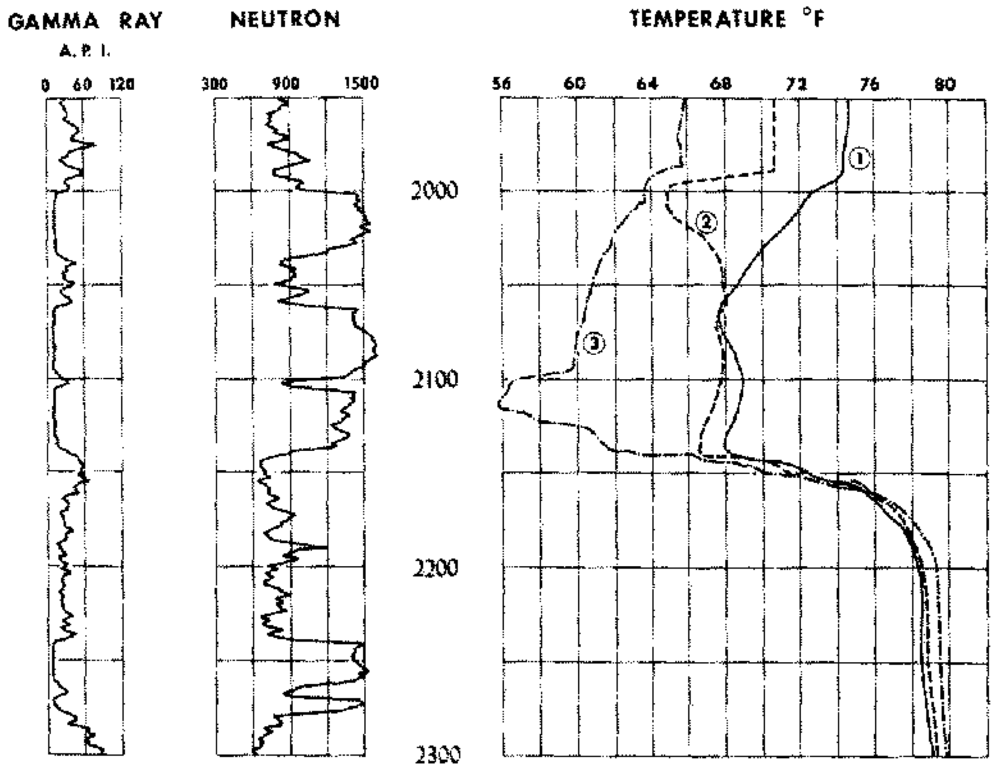

Figure 11

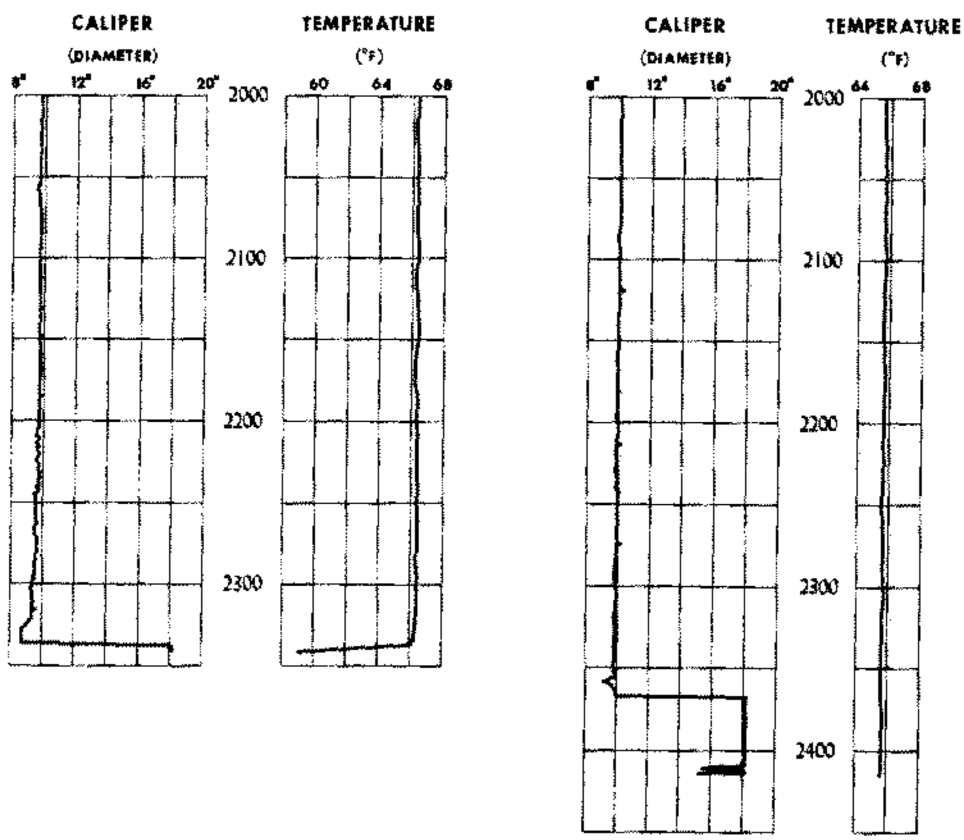

Figure 12

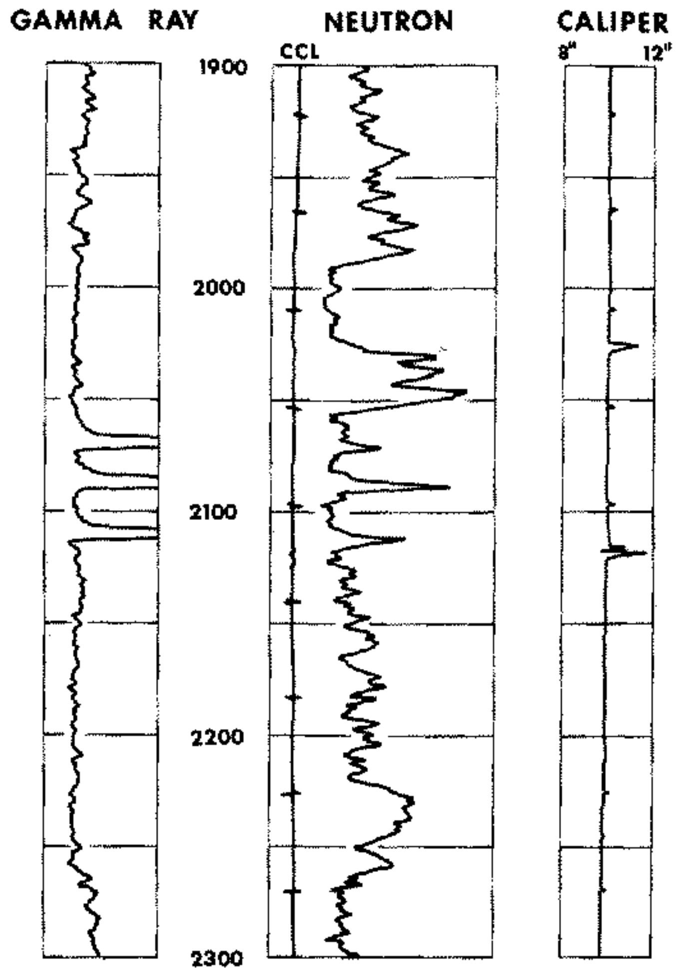

Figure 13

well and indicates a hole in the casing from 2, 025 to 2, 028 feet. Another hole exists from 2, 116 to 2, 120 feet. An examination of the lengths of the joints in which the holes exist indicates corrosive action rather than parting of the pipe.

An unusual condition that existed in a producing well is displayed in Fig. 14. The well had been a producer since its original completion date. Ten and three fourth-inch casing was the long string with six-inch transit used as a liner. The production had declined remarkedly at the time of logging Curves # 1 and # 2, a Gamma Ray-Neutron Log. Curve # 3, a Caliper Log, recorded on the same trip to the well indicated a sizeable build-up inside the liner and casing. An inspection at the surface indicated a gyp forming on the casing. Immediately, the well was converted to an injection well. The injection rate started slow and gradually rose to the expected rate. Ten months after injection was started, Curve # 4 was recorded with the Caliper indicating well bore diameters comparable to nominal casing diameters.

Figure 15 is a sketch of a Cement Bond tool in a cased well bore. The Cement Bond tool is an acoustic device utilizing a single transmitter and receiver. The spacing between the transmitter and receiver is normally six feet. The tool is centralized in the casing and utilizes the fluid in the well bore to transfer the acoustic signal to the pipe and the medium beyond the pipe. A borehole gain in the receiver section that may be controlled at the surface is most essential. At the surface an ocilloscope is utilized to monitor the recorded signal. An electronic gate in the surface equipment is utilized. The width and position of the gate can be varied in time. The amplitude of the received signal is recorded as the amplitude log. The transit time for arrival of the first event is recorded as the transit time curve.

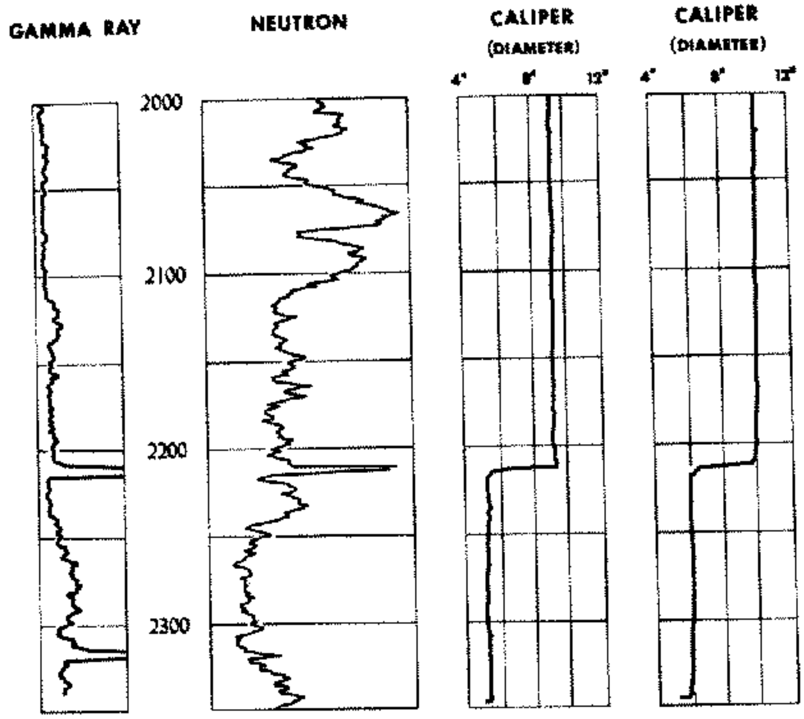

Figure 14

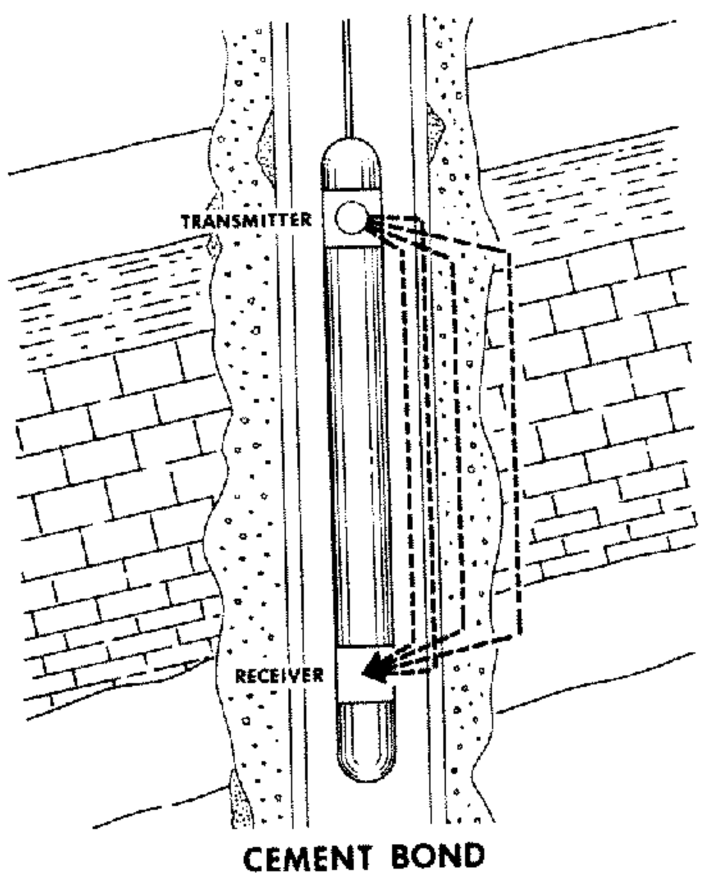

Figure 15

A sketch of a Cement Bond tool is portrayed on the left side of Fig. 16. The signal indicated in "A" is that of free pipe with the total travel time for five and one-half-inch casing and showing the width and position of the electronic gate. "B" is a signal where formation transit time greater than pipe time is experienced. The casing to cement and cement to formation bond is good quality resulting in the signal taking on the transit time of the formation. "C" represents a signal where formation transit time is less than pipe. The resultant is a transit time slightly lower than pipe with low amplitude. "D" indicates the signal resulting from formation transit time considerably less than pipe. The resultant is a transit time much lower than pipe time and the amplitude of the sinusoidal wave coming under the electronic gate indicates high amplitude. Here, there at first appears to be conflicting information for the interpretation of the Cement Bond log. Experience, however, has shown that a good cement bond does exist when these conditions are indicated by the log.

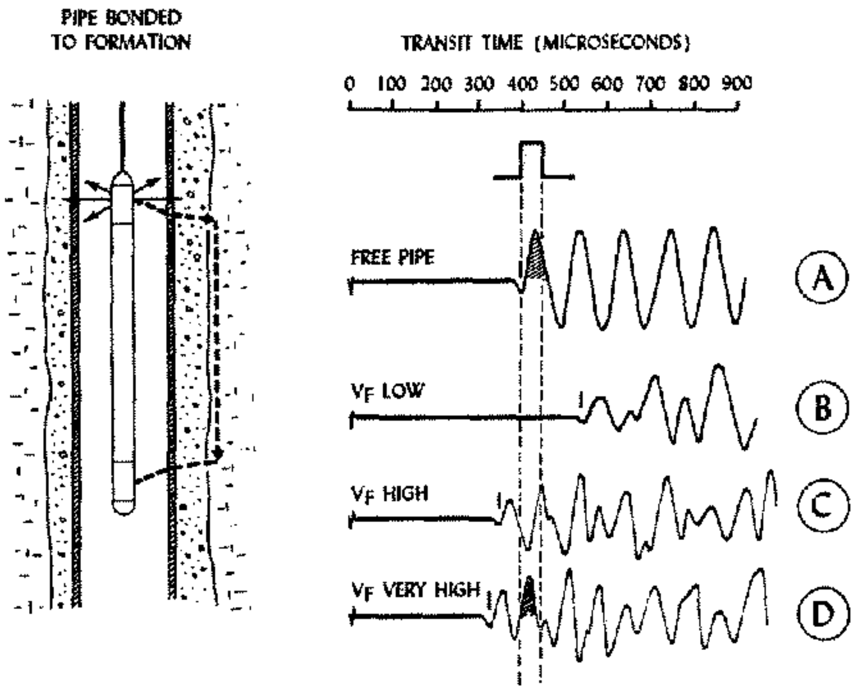

Figure 16

An example of a Gamma Ray-Neutron and Cement Bond Log are presented in Fig. 17. Curve # 1 is a Gamma Ray, # 2 a Casing Collar Locator, and # 3 a Neutron log. Curve # 4 is the Transit Time Curve in microseconds per foot. The dotted line is transit time for ten and three-fourth-inch casing. In the poor bond section the recorded transit time is very close to pipe time. The casing collars are apparent in the poor bond section. Curve # 5 represents the amplitude recorded under the electronic gate. Note the casing collars indicated at 2, 074, 2, 115, and 2, 134 feet in the poor bond section.

One of the logs used in the oil and gas industry that has not, up to this time, been used in the solution brine well industry is the Salinometer Log. The log shows a continuous recording of the mud resistivity in the well bore. Measurements are made on the inside of the tool where only the mud resistivity can influence the reading of the four electrodes. The product is the mud resistivity in values of ohms per meter cubed.

An example of the use of the Salinometer Log is shown in Fig. 18. These logs were taken for the Atomic Energy Commission under field supervision of Fenix & Scisson at the request of United States Geological Survey for use in geological and hydrological interpretation as part of

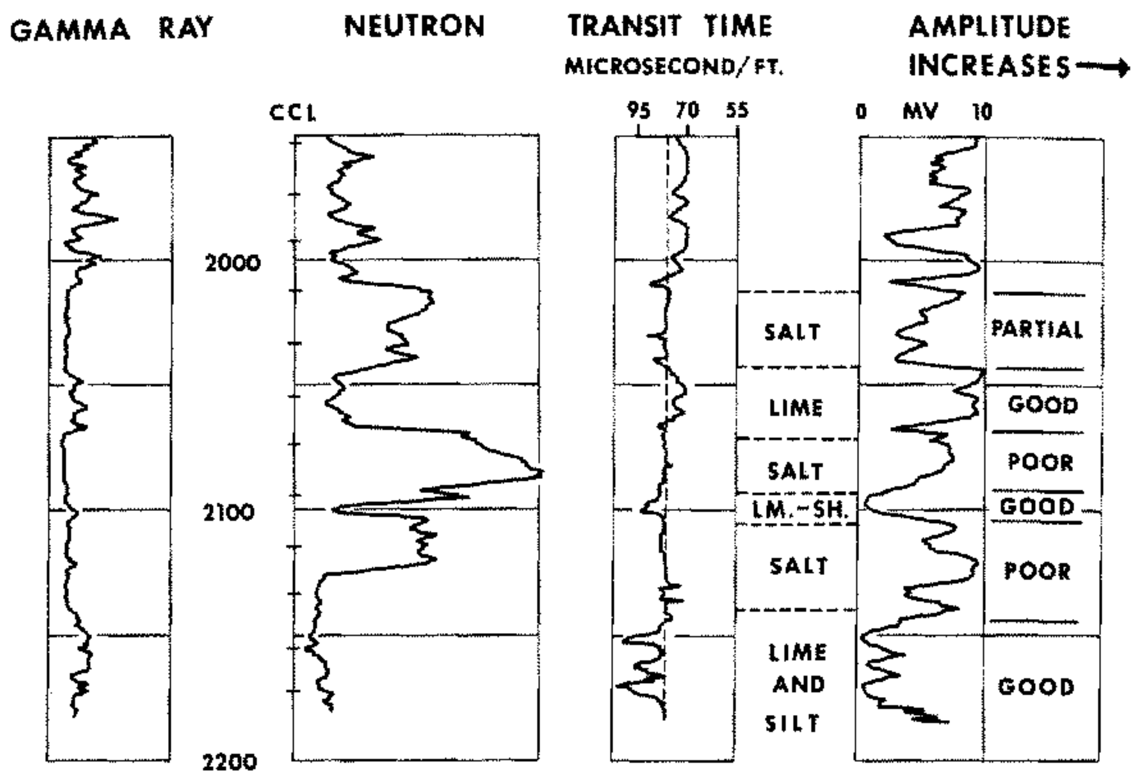

Figure 17

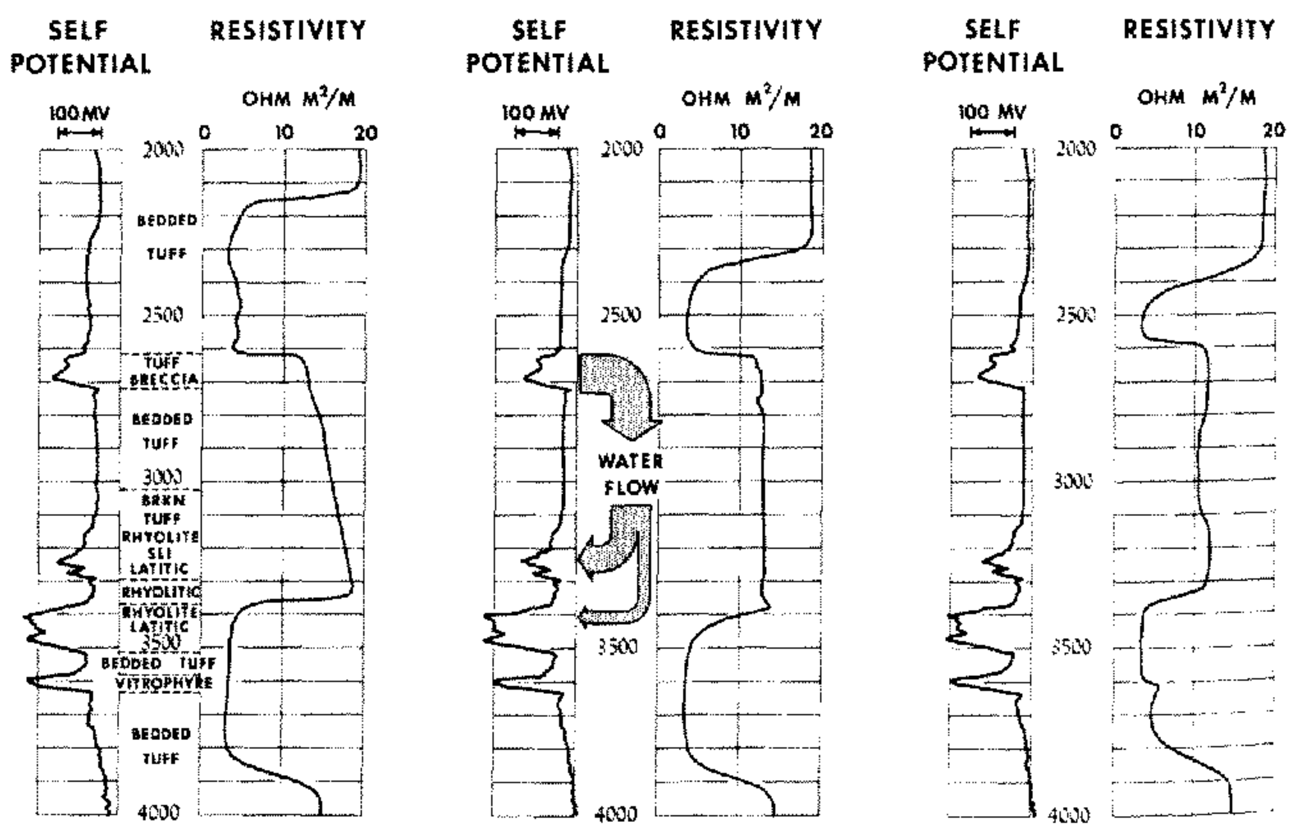

Figure 18

the Atomic Energy Commission's Nevada Test Site. The logs were run to determine the entrance of water and flow of same in the well bore. The static fluid level was 2,000 feet. Salt water was prepared and placed in the well bore at 3,900 feet and above. Curve # 1 is a Self Potential with calibrations set at 100 millivolts per inch on the chart. Note the zones of indicated porosity and permeability on this curve. Curve # 2 is the resistivity of the well fluid as determined by the salinometer. Note the resistivity increase between 2,520 and 3,360 feet. Curves # 1 and # 2 are recorded as soon as the drill pipe through which the salt water was placed in the well bore was removed. Curve # 3, and S. P., and Curve # 4, a Salinometer, was recorded while logging down two hours after Curves # 1 and # 2. Note the interface has moved down from a depth of 2,150 to 2,325 feet. Also, the resistivity values between the depths of 2,150 to 3,400 feet has become constant. Curves # 5 and # 6 were recorded from the bottom up one hour after Curves # 3 and # 4. A small increase in resistivity is indicated at 3,600 feet. The resistivity between depths previously noted has decreased slightly. The salt-fresh water interface has moved down from 2,325 to 2,400 feet. An examination of the Self Potential and Salinometer curves indicated water flowing from the zone at depths 2,600 to 2,700 feet down to the zones at 3,200 and 3,400 feet.

Conclusions

From the above examples, it can be concluded that wire line tools developed for the oil and gas industry can have great utility in brine wells. There is room for improvement in tool design and logging techniques to create better results. This will come about only through cooperative efforts.