BECAUSE of the considerable cooling resulting from the expansion of gas, many petroleum reservoirs can be located by temperature measurements made in wells filled only partly with mud.

Temperature

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THE nature of the fluids contained in reservoirs is usually difficult to determine in situ even when modern logging methods are applied. On the other hand, the problem may frequently be solved satisfactorily when small quantities of these fluids are permitted to enter the bore hole.

A number of properties can be successfully investigated for this determination, among which the temperature of the fluids occupies a leading place.

Although temperature measurements can solve a number of fluid problems they have, like any other method, certain limitations which either prohibit their general use, or make difficult the interpretation of the data. These limitations are as follows:

1. The temperature changes observed in a bore hole are not always caused by fluid intrusions only.
2. Temperature anomalies are a transient phenomenon which is frequently of short duration.
3. Oil which does not release an appreciable amount of free gas has approximately the same thermal properties as water, and usually cannot be distinguished from it.

Two main problems can be frequently solved by temperature measurements in drill holes:

A. Location of petroleum reservoirs in wells which do not contain drilling fluid.

B. Production problems.

A few examples of these applications will be discussed.

Gas Reservoirs

In rotary wells the density of the drilling fluid is usually such that the pressure of the mud at any point of the hole is greater than the formation pressure. Therefore, there is generally no fluid intrusion from the beds penetrated into

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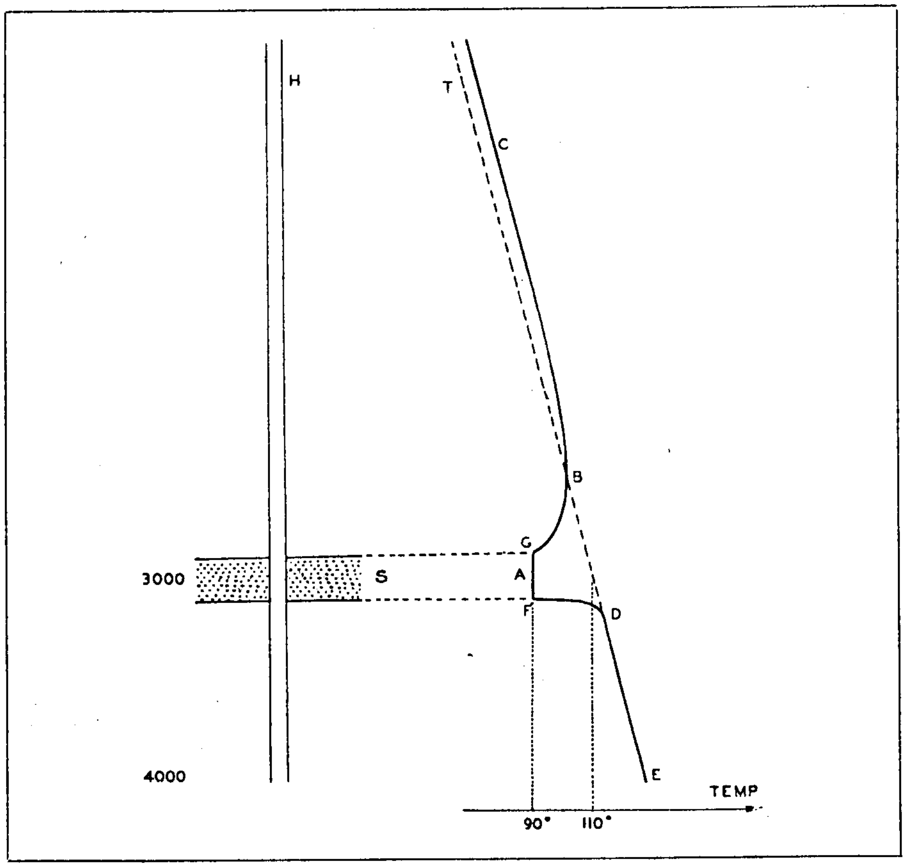


Figure 6-1 (top). Temperature anomaly produced by gas entry (hypothetical).

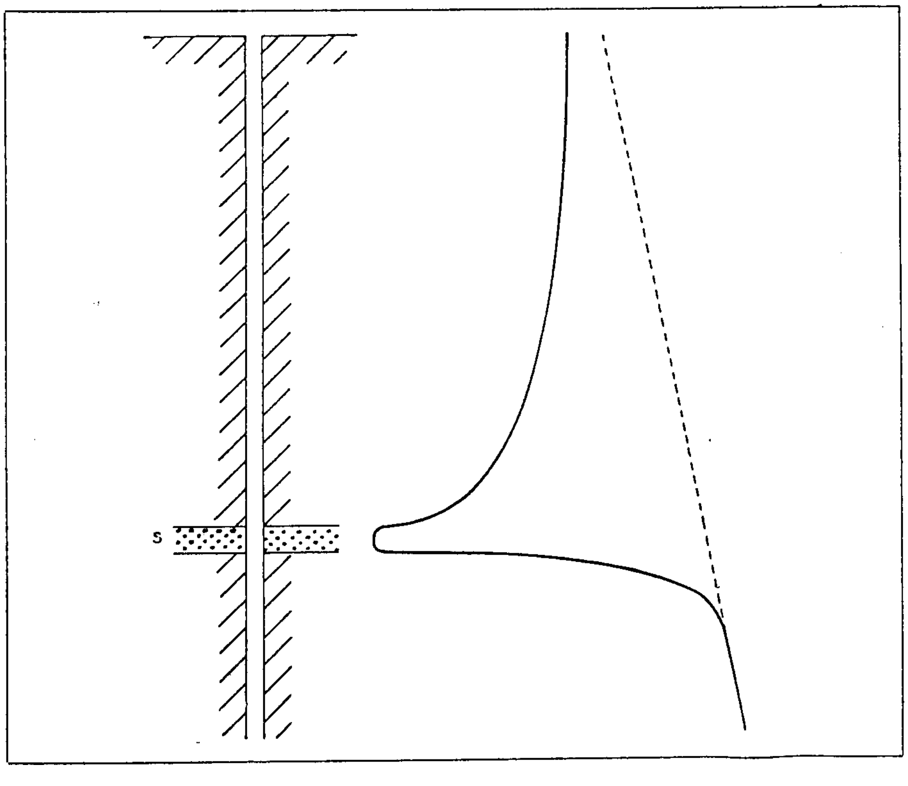


Figure 6-2 (bottom). Depth-temperature graph in a well producing a large quantity of gas from a high-pressure reservoir (hypothetical).

WELL LOGGING

Part 6

Wells Not in Thermal Equilibrium

B. Fluid Intrusions

the bore. On the other hand, in wells drilled by the cable-tool method there is an almost continual influx of fluids into the hole. When the well traverses a gas sand, an appreciable quantity of gas is released, and its expansion is accompanied by a temperature decrease. Evidently the temperature is minimum where the greatest expansion takes place, namely directly opposite the reservoir.

Referring to Figure 6-1, H is a cable-tool hole 4000 feet deep, for example, having penetrated a gas sand S at 3000 feet. Suppose this sand was sealed while drilling proceeded from 3000 to 4000 feet and that the hole contained only air. A temperature graph T made under this condition would show that the temperature steadily increases with depth, and in first approximation it can be assumed that graph T is substantially a straight line indicating a temperature of 110° at 3000 feet. Suppose now that a certain quantity of gas is released from the sand and that a recording thermometer is constantly held in this mass of gas. The pressure of the gas, while escaping, will drop considerably and the gas temperature will decrease from 110° to perhaps 90° (section A of graph). Because of its low density, the gas will rise in the hole while finishing to expand to atmospheric pressure. Since its temperature is much less than that of the formations, it will cool the latter while ascending, and in turn will be warmed by them, until such depth is reached that a temperature equilibrium is attained (point B). Above point B the gas, while rising, comes in contact with formations which are colder than itself and there is an exchange of heat in the opposite direction. Because of thermal lag, above point B the gas remains warmer than the formation with which it is in contact.

Below S there is no great movement of gas (because of the difference in density), and heat is transferred almost only by diffusion and conduction. The resulting temperature distribution is shown by arc ADE.

A complete depth-temperature graph is therefore as shown by curve CBADE showing two breaks, F and G, at the boundaries of the reservoir.

The magnitude of the temperature anomaly at S and the length of arc GB depend primarily upon the pressure drop at the level of the reservoir and upon the quantity of gas released per unit time. When these two factors have large values, the temperature drop is considerable and the temperature of the gas at the top of the well may be much less than the ground temperature at that level. (Figure 6-2.)

If there is another gas reservoir S' above S, the resulting anomaly is superimposed on that described above. For example, if the quantity of gas released by S' is much less than that released by S, the temperature graph is basically as shown on Figure 6-3. In the opposite case, the log is more or less as indicated on Figure 6-4, all other factors remaining the same.

If the gas escapes from a single fissure (fractured limestone, for example), the temperature anomaly is extended over a shorter distance (Figure 6-5).

Oil Reservoirs

When an oil reservoir is tapped, part of the gas dissolved comes out of solution and escapes also into the well. The resulting thermal anomaly is evidently almost identical to that which would be obtained if the same quantity of gas had escaped alone from the reservoir.

However, because the quantity of gas dissolved in oil is relatively small, the cooling due to an inflow of oil is less than that produced by free gas, all other factors remaining the same. This difference is of considerable practical importance because it frequently permits determining the approximate base of the gas in wells which are not filled with drilling fluid, whereby correct completion for low gas-oil ratio is possible. There are, however, no fast rules for the solution of this problem and usually some local experience is necessary. Also, the correlation of temperature readings with other data is profitable.

Referring to Figure 6-6 for example, the largest temperature anomalies are situated above 3310. Pipe was set at 3320 and the well came in with a small GOR.

There are cases, unfortunately, where the gas-oil contact cannot be determined from temperature data. This is especially true when the petroleum is found in fractured reservoirs. The erratic nature of the formation is probably responsible for this condition. Figure 6-7 represents a temperature log obtained in a West Texas well having penetrated a fractured limestone. From other data it is known that the gas-oil contact is in the neighborhood of 4880. The log fails to show any significant anomaly near this point.

Figures 6-8, 6-9 and 6-10 are early temperature graphs obtained by, or under the direction of, C. E. Van Orstrand. Although only spot readings were taken, the graphs illustrate well some of the remarks offered above.

In wells filled partly with mud or water, it is more difficult to determine positively the position of petroleum reservoirs because the pressure differential, and therefore the temperature anomaly, is less. If the fluid level is sufficiently high, there is no oil or gas entry and the temperature changes exhibited by the log are usually not related to the petroleum reservoirs.

Production Problems

To suppress or reduce the amount of water which is produced from many oil wells it is necessary first to locate the

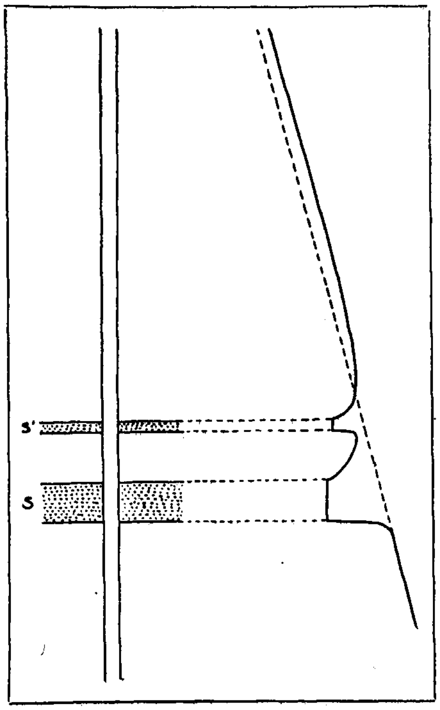


Figure 6-3. Depth-temperature graph in a cable tool well having penetrated two gas sands (hypothetical).

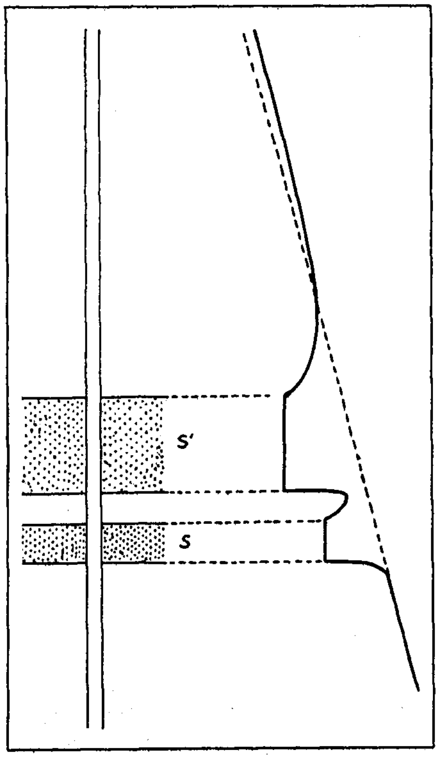
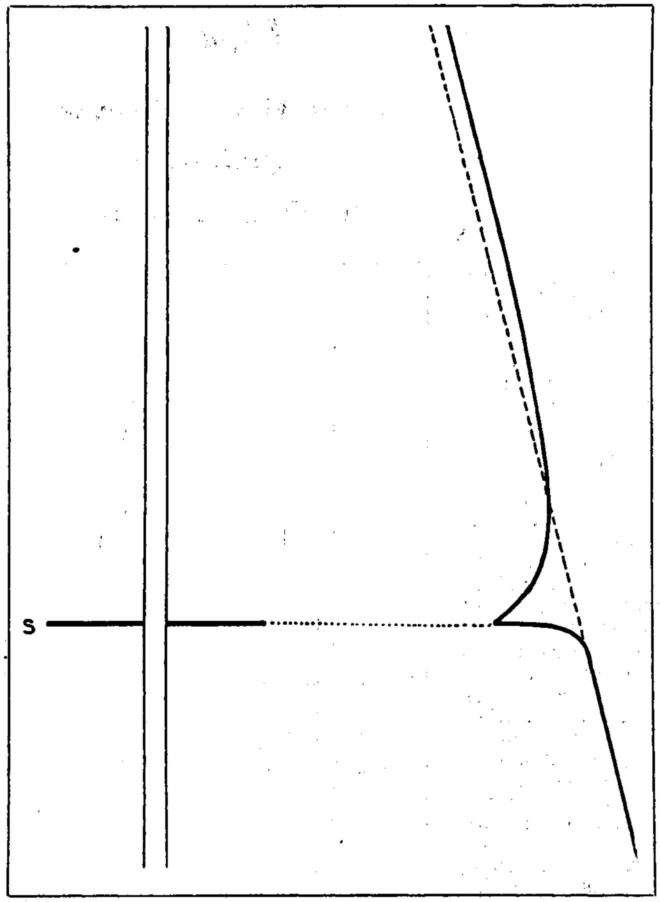


Figure 6-4. Depth-temperature graph in a cable tool well having penetrated two gas sands (hypothetical).



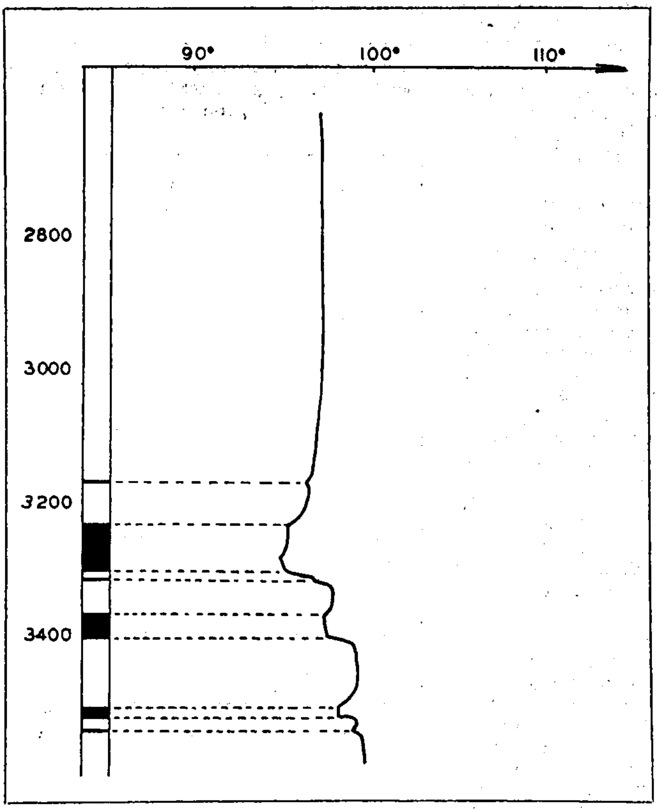


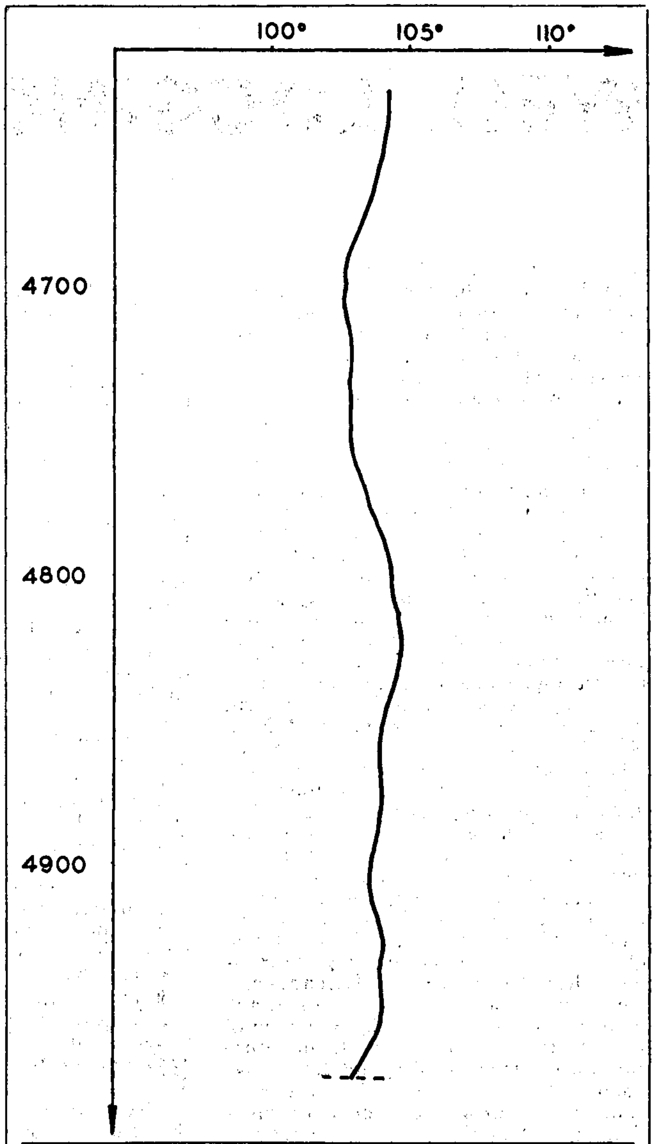
Figure 6-5 (top left). Depth-temperature graph in a cable tool well having penetrated a single fracture containing gas (hypothetical).

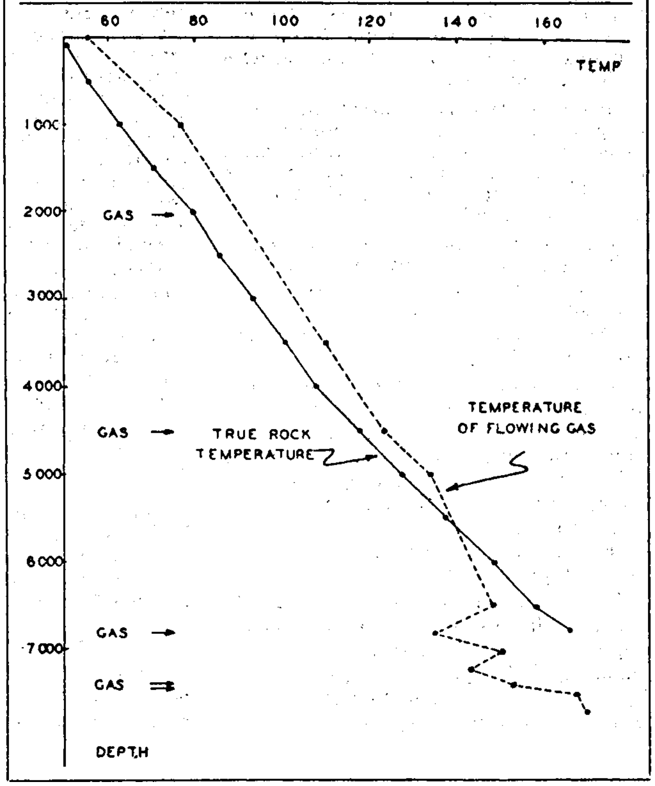
Figure 6-6 (lower left). Temperature graph from a West Texas well having penetrated porous dolomite containing oil and gas.

Figure 6-7 (upper right). Temperature graph from a West Texas well having penetrated a fractured lime section containing oil and gas.

Figure 6-8 (lower right). Depth-temperature graph in a flowing well.

After Van Orstrand, 1930. Courtesy API





point of entry of water. Temperature measurements frequently permit solving the problem. Basically, the method consists in setting up proper thermal conditions in the well in order to produce relatively large temperature anomalies from the flow of water This conditioning of the hole is usually achieved by circulating mud or gas at such a temperature that good contrast is obtained from the water. In a few rare instances the thermal state of the well is such that no preliminary conditioning is necessary.

Referring, for example, to Figure 6-11, the oil production from the well shown to the left stopped gradually while large quantities of water were produced. A temperature survey made while the well was flowing showed an upward migration of fluid (water) from the bottom of the lower set of perforations. A second survey made after the well was shut in disclosed that this fluid was entering the upper set of perforations at 5510 feet and presumably was flooding the oil sand situated at this level. Pressure traverses confirmed the foregoing interpretation. Plugging back to 6150 feet shut off the water.

Another case of successful water location is shown on Figure 6-12. The well had casing to 2937 feet and open hole from the shoe to 3026 feet. Circulation was made with 9.4-pound mud to clean out bottom, the pipes were pulled out, and a temperature survey obtained (run No. 1). The well was then bailed and bailing continued until the fluid level stopped going down. Approximately 600 lineal feet of fluid was removed. Run No. 2 was made and a sharp increase in temperature was indicated on bottom. The well was again bailed until the fluid level could not be reduced (approximately 60 lineal feet of fluid was removed). Run No. 3 made thereafter confirmed the results of run No. 2. A cement plug was placed in the bottom of the well and the water shut off.

Figure 6-13 represents two temperature runs made to locate the point of gas entry in an oil well. The first survey (plain line) was made while the well was flowing through casing, with tubing shut in. The graph indicates that the greater part of the gas is coming from 9280 feet with a tapering off to bottom. The shutin survey shows the temperature drifting towards the normal geothermal gradient, indicating that no formation was taking gas appreciably.

Interpretation of Data

The use of temperature measurements in wells will become more valuable when the interpretation of the data becomes more positive. Good progress is being made by building up a background of knowledge from the many surveys made in wells under various conditions in different areas of this country, and by coordinating the results with all other information available, in particular pressure traverses.

Acknowledgment

The writer is greatly indebted to C. R. Dale, Dale Company, Los Angeles, for the logs and data contributed to the present article.

(Additional figures on following page.)

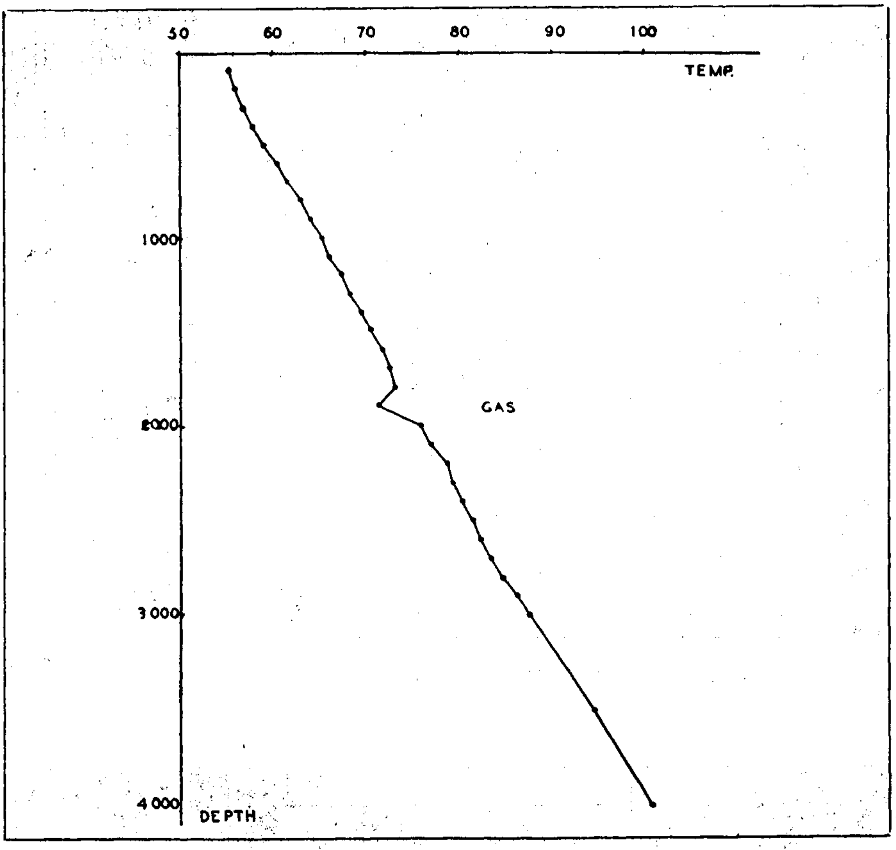


Figure 6-9. Depth-temperature graph of a West Virginia well.
After Van Orstrand, 1918. Courtesy West Virginia Geological Survey

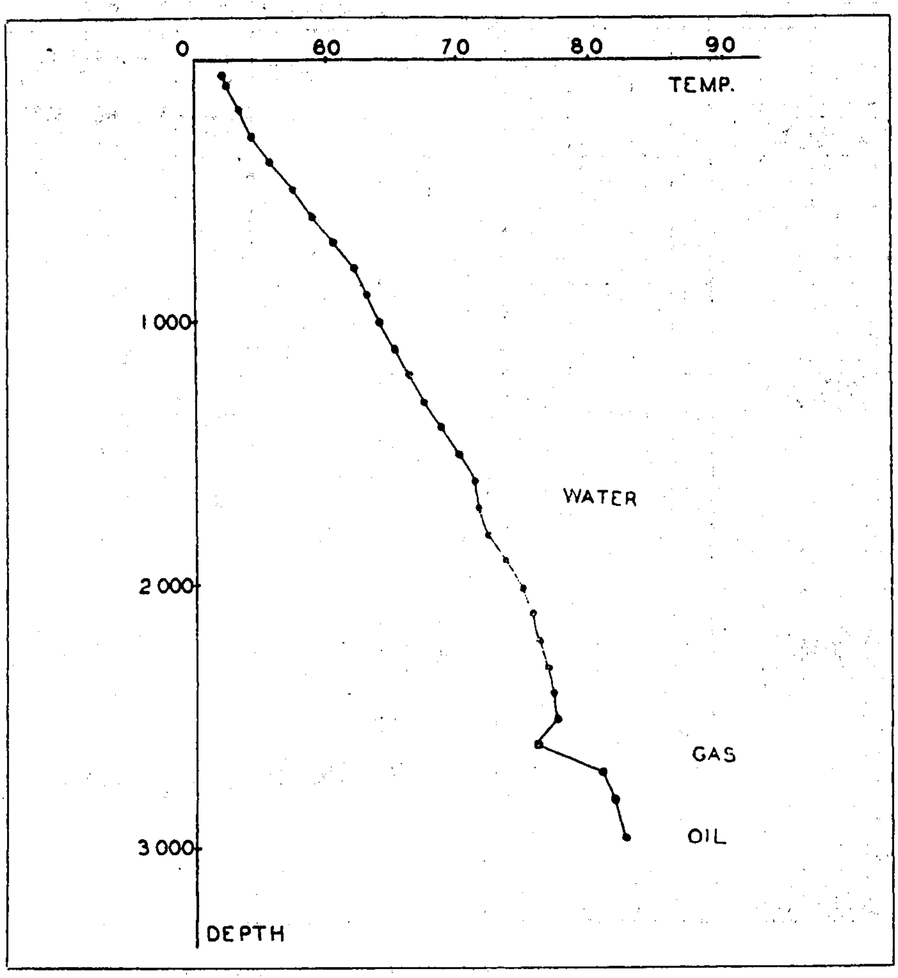
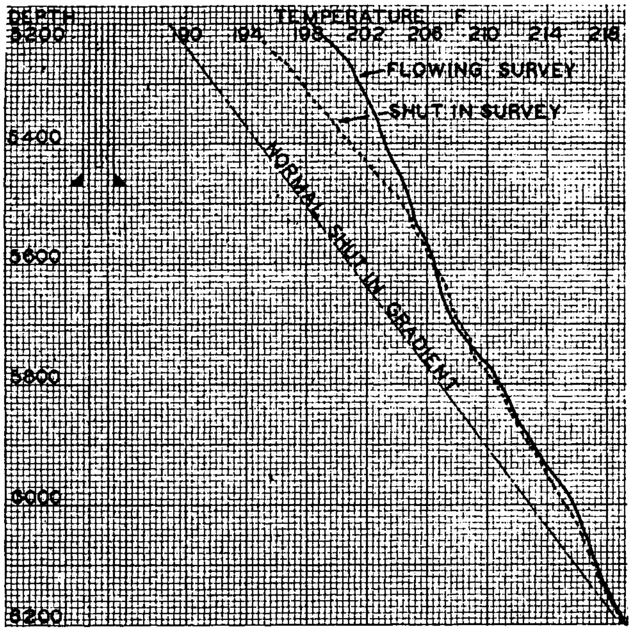


Figure 6-10. Depth-temperature graph of a West Virginia well.
After Van Orstrand, 1918. Courtesy West Virginia Geological Survey



.Figure 6-11. Investigation of water migration in a California well.

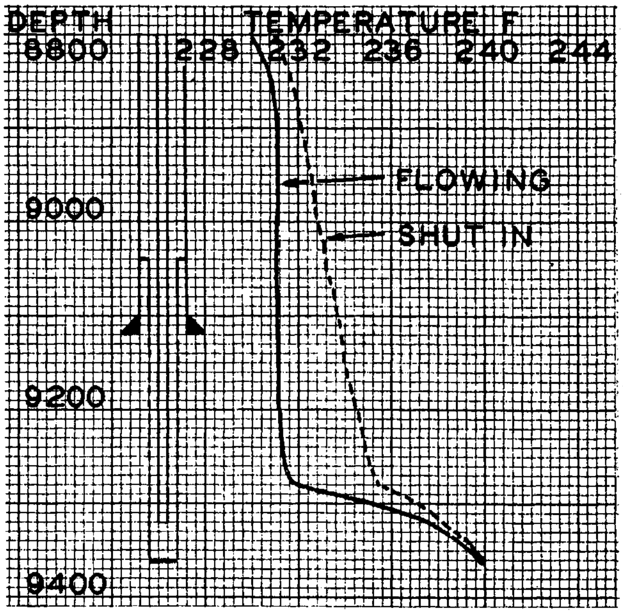


Figure 6-13. Location of a point of gas entry in a California well.

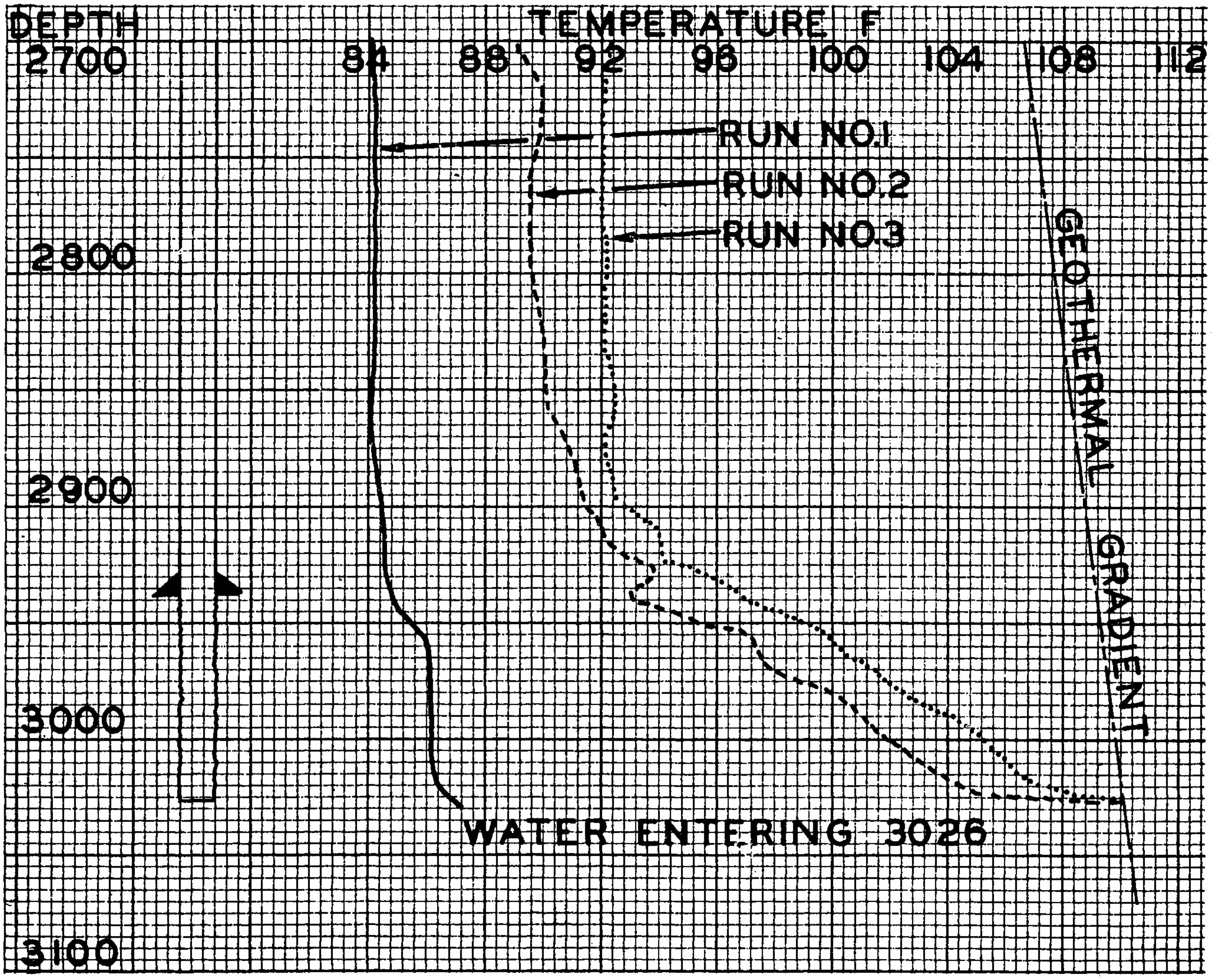


Figure 6-12. Location of a water flow in a California well.

These three charts courtesy Dale Company