APPLICATIONS OF THE CARBON/OXYGEN LOG IN JOHNSON (GLORIETA) FIELD

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ABSTRACT

In June 1978, the Carbon/Oxygen (C/O) Log began aiding formation evaluation in the Gorieta reservoir of Johnson Field, a moderately porous carbonate trend in central Ector County, eight miles northwest of Odessa, Texas. Production there is from four separate reservoirs - the Grayburg - San Andres, the Holt, the Glorieta, and the Upper Penn. Until recently, Glorieta development was limited by lack of oil shows in drilling samples, by poor drillstem test performance, and by high water saturations calculated from open-hole logging packages.

But, results of the Carbon/Oxygen Log substantially contradict open-hole log interpretations and have led to successful completions in zones previously believed to be wet. Based on these data, eleven wells have been either drilled or recompleted to the Glorieta.

The paper will review the history of Glorieta development in the Johnson area prior to use of the C/O Log and will briefly discuss the operation of the logging system. It will describe the logging suite now in use, showing a comparison of open-hole and C/O Log interpretations for the same wells. The C/O Log has seen only limited use in the carbonate formations of the Permian Basin, but possible suitability of the log in other West Texas applications is suggested.

Information from this project will help other operators to evaluate the suitability of the logging system in areas where open-hole logs are unavailable or unreliable.

Principal conclusions drawn from the project are as follows:

1. Open-hole logging suites used in the area did not yield reliable S_w data in the Glorieta.

2. The Carbon/Oxygen tool has applications in carbonate reservoirs such as the Glorieta.

3. Porosity limitations on the use of the C/O tool have not been determined. Qualitative accuracy has been obtained in this project through a porosity range of approximately 10-20%.

INTRODUCTION

Field History

The Johnson Field is located in Ector County, some eight miles northwest of Odessa, Texas (Fig.1). Production in the area comes from four zones, the Grayburg - San Andres, Holt, Glorieta, and Upper Penn. (Fig. 2). Development of the three deeper zones began with completion of the Johnson Deep Unit (JDU) No. 1 in April 1973. Open-hole log analysis indicated high water saturations in most of the poentially productive intervals in the Glorieta, and the well was completed dually in the Holt and Penn. formations.

Three subsequent wells were drilled as Holt or Holt-Penn. producers. When the productive limits of the Penn. were reached, a Glorieta completion was attempted in the JDU No. 5. The attempt was successful, and a total of nine wells on the east side of the field were eventually completed as Glorieta producers.

Because of poor shows in drilling samples, lack of encouragement from the open-hole logs, and an unsuccessful drillstem test in the JDU No. 2 well, no additional development was attempted on the west side until 1977. In November 1977 the Sun Johnson "D" No. 6 well, located on the western edge of the field, was successfully recompleted. Production was from an upper Glorieta zone. The JDU No. 13, drilled as an offset, also established Glorieta production although considerable water was encountered.

Based on these tests it appeared that the interpretations drawn from conventional open-hole resistivity logs were not reliable for the Glorieta; therefore, the Carbon/Oxygen (C/O) Log was run in the JDU No. 1 well, which had been cased through the Glorieta but completed in another zone. The Carbon/Oxygen system was chosen because it could be run inside casing and because the log measurements would be substantially independent of water salinity.

Glorieta Lithology and Reservoir Data

The Glorieta is a sucrosic dolomite with matrix porosity and some evidence of natural fracturing. Entrapment is primarily stratigraphic, with a combination of up-dip reservoir termination and vertical relief affecting the trap. The top of the Glorieta occurs at a depth of -2360' to -2440' subsea (SS) in the developed portion of the field. Gross thickness of the formation is 300', but the productive limit is determined by an oil/water contact at -2525' SS.

In the Johnson Glorieta, there are three identifiable zones of porosity separated by interbedded stringers of dense shaly or silty dolomite. Matrix porosity ranges from a cutoff of 8% to a high of 25% with the average about 16%. Some indications of natural fracturing have been observed in cores, but this condition is not believed to be extensive.

The oil/water contact of -2525' SS was determined for the lower zones from core data on two wells in the field. No determination has been made on whether this contact is common to all three zones. Water production histories on individual wells suggest that some stringers above that point may be waterbearing over portions of the field.

Open-Hole Interpretations

Early evaluation of the wells was by an open hole logging suite consisting of a Compensated Neutron, Compensated Density Log, and Dual Laterolog. While this technique appeared to be adequate for evaluating the Pennsylvanian and Holt sections, open-hole log analysis through the Glorieta remained pessimistic.

Figure 3 shows a computerized analysis through the Glorieta on JDU No. 13 using an R_w value of .15. Note the high water saturations, especially in the upper part of the section.

However, the well was completed in 1977 in the interval 5442' to 5514' with a production rate of 95 barrels of oil per day and 195 barrels of water per day. It became obvious that the apparent high water-saturation values derived from the core and logs were at best misleading. Considering this, the operator decided to re-evaluate the Glorieta behind casing in selected wells using the Carbon/Oxygen Log.

Carbon/Oxygen Log Theory and Interpretation

The Carbon/Oxygen Log utilizes a high energy pulsed neutron source.[1,2] It has long been known that upon high-energy neutron bombardment, every element emits gamma-rays of a specific energy level. By monitoring the quantity of gamma-rays of various specific energy levels, the relative amounts of the individual elements can be determined. The Carbon/Oxygen Log allows a measurement of the relative amounts of carbon and oxygen present in the formations.

Both hydrocarbons and formation water contain hydrogen, but of these two, only hydrocarbons contain carbon and only water contains oxygen. Gamma-rays resulting from the neutron bombardment are measured by a scintillation spectrometer calibrated to count pulses in the energy range of carbon and oxygen - 4.43 mev and 6.13 mev respectively. The ratio of carbon to oxygen can then be used to determine hydrocarbon saturation. A typical capture spectrum is shown in Fig. 4.

While one is primarily interested in the Carbon/Oxygen ratio of the material filling the pore spaces, one must also be aware of the influence of carbon contained in the matrix. To this end the resultant gamma-rays also allow one to determine calcium and silicon. The ratio of calcium to silicon aids in the log evaluation by indicating variation in the amount of $CaCo_3$ present in the matrix material. By knowing the amount of $CaCO_3$ we can remove the contribution of the carbon in the carbonate matrix from the carbon/oxygen ratio. In practice, this is done by normalizing the two ratio curves. C/O and Ca/Si, below the oil/water contact or in a known waterbearing zone.[3]

Since Carbon and Oxygen measurements are not affected by formation water salinity, the Carbon/Oxygen Log, unlike conventional resistivity logs, has proven to be a reliable indicator of hydrocarbon saturation. In some cases, the Ca/Si curve may be influenced by salinity, but the effects are usually minor and can be corrected during normalization. Lithologic variations are handled in the same manner.

Field Results

The initial Carbon/Oxygen Log was run in this field during a recompletion attempt on the Johnson Deep Unit No. 1. The open-hole porosity logs are shown in Fig. 5 with calculated porosity and water saturation values listed adjacent to the depth track. Again, the open-hole log calculations indicated the Glorieta to be marginal. Water saturation values in Zone 1 range from 80% to 100% - interpreted as water productive. Zone 2 shows water saturations from 37% to 68% - probably water productive. This leaves the upper portion of Zone 3 as the only probable hydrocarbon productive interval in the Glorieta based upon the open-hole log calculations.

The correct R_W for water saturation calculations in this area is uncertain. Typical R_W values for other Glorieta reservoirs are in the range of .06 to .07 ohm-meters at $77^{O}F$. However, producing water samples from Johnson area wells yield R_W numbers in the range of .26 - .3 ohm-meters.

Regardless of the correct R_W value, saturation calculations based on resistivity logs do not appear to be consistent. For example, the porosity and resistivity values for Zone 1 agree closely with those of the portion of Zone 3 below the known oil/water contact. Therefore, no matter what R_W is chosen, calculated water saturations for these zones will be similar. As the lower zone is known to be wet, the interval in Zone 1 would also appear to be waterbearing. Subsequent analysis with the C/O Log and production data from the well show that this is not the case.

Figure 6 shows the C/O Log with the C/O curve overlayed with the Ca/Si curve and normalized below the oil/water contact at 5542' (-2524'SS). The crosshatched sections mark the potential hydrocarbon intervals as indicated from the C/O Log. Zone 1 shows good hydrocarbon saturation from 5410' to 5434'. Zone 3 indicates good hydrocarbon saturation from 5492' to 5500' and from 5526' to 5536'.

Based on this information the well was perforated from 5414' to 5431' in Zone 1 and from 5492' to 5498' in Zone 3. Zone 2 was not perforated due to its lower apparent hydrocarbon saturation and due to the operator's desire to keep water production to a minimum. The lower interval in Zone 3 was not opened because of its close proximity to the oil/water contact.Following a 3000 gallon acid job, the well tested at 271 BOPD and no water on a 10-64" choke with GOR of 173.

Because there was some doubt as to the effective porosity range for the application of the C/O Log, it was pulled through the Holt formation. The Holt is a clean limestone section with an average fieldwide porosity of 10.7% based on log and core analysis data. An oil/water contact at -2290' SS has been identified by resistivity logs and core data, and it has been confirmed by selective testing.

In the example shown, the C/O Log was renormalized in the lower Holt interval. The crosshatched area shows hydrocarbon-bearing intervals. This interpretation corresponds almost exactly with the interval originally completed and with the oil/water contact determined from the open-hole logs.

The next well in which the C/O Log was run was the JDU No. 2 which had been a single Holt producer prior to workover. No open-hole logs were obtained through the Glorieta section because of poor hole conditions. However, a drillstem test from 5402' to 5484' (covering Zones 1 and 2) recovered 1000' of gas, 375' of oil and gas cut mud, and 90' of salty sulfur water. (Fig. 7 - CN/GR through pipe). Based on the C/O Log overlay, as shown in Fig. 8, the well was perforated from 5483' to 5494' and from 5503' to 5509' in Zones 2 and 3. Note that Zone 1 was not opened due to the low hydrocarbon saturation indicated on the C/O Log. After treating with 3000 gallons of acid, the Glorieta tested at 334 barrels of oil per day and no water, flowing on a 10-64" choke with a gas/oil ratio of 155. The well returned to production as a Holt-Glorieta dual.

Although the JDU No. 1 and No. 2 are 40-acre offsets and are structurally comparable, the C/O Log results in Zone 1 are substantially different for the two wells. In the JDU No. 1, Zone 1 showed the highest indicated hydrocarbon saturation in the well, and it was perforated along with the upper part of Zone 3. In the JDU No. 2 well, the overlay shows much less separation in Zone 1, and some of the highest porosity intervals appear to be waterbearing. On this basis, Zone 1 was not opened in the JDU No. 2 well. The interval perforated included the upper part of Zone 3 and a portion of Zone 2 not present in the JDU No. 1 well.

CONCLUSIONS

To date, eight new wells have been drilled and three have been recompleted in the field. Present practice is to perforate based on a cased-hole Gamma Ray - Compensated Neutron Log and the Carbon/Oxygen Log. No open-hole logs are being run in newly drilled wells. Production results have been extremely favorable and demonstrate the applicability of the Carbon/Oxygen Log in moderately porous carbonate reservoirs such as the Glorieta.

No selective testing has been done to fully evaluate the log results. Consequently, a minimum porosity cut-off for the C/O Log has not been established. However, qualitative accuracy of the log has been realized in this project through a porosity range of 10% to 20%.

The results obtained to date are sufficiently promising to warrant further study. Additional field development is planned using the Carbon/Oxygen Log.

REFERENCES

1. Lock, G. A. and Hoyer, W. A.: "Carbon/Oxygen (C/O) Log; Use and Interpretation," Journal of Petroleum Technology, Sept. 1974, 1044.

2. Culver, R. B., Hopkinson, E. C., and Youmans, A. H.: "Carbon Oxygen (C/O) Logging Instrumentation," SPE Journal, Vo. 14, No. 5, Oct. 1974.

3. Heflin, J. D., Lawrence, T., Oliver, D., Koenn, L.: "California Applications for the Continuous Carbon/Oxygen Log," API Joint Chapter Meeting, Bakersfield, California, Oct. 1977.

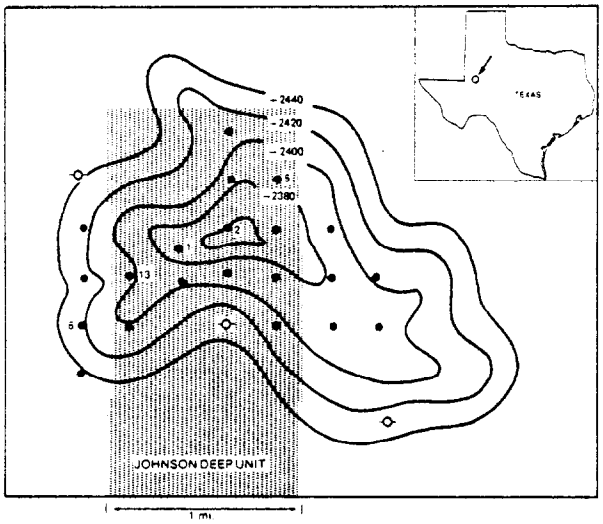

FIGURE 1—LOCATION AND STRUCTURE JOHNSON (GLORIETA) FIELD ECTOR COUNTY, TEXAS

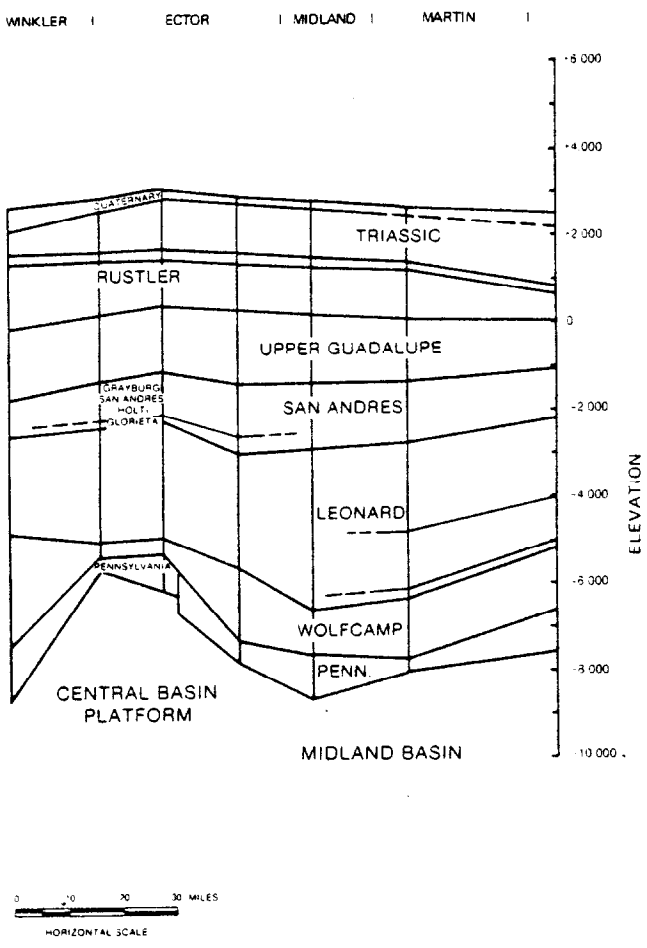

FIGURE 2—PARTIAL GENERALIZED CROSS-SECTION OF THE PERMIAN BASSIN, WEST TEXAS

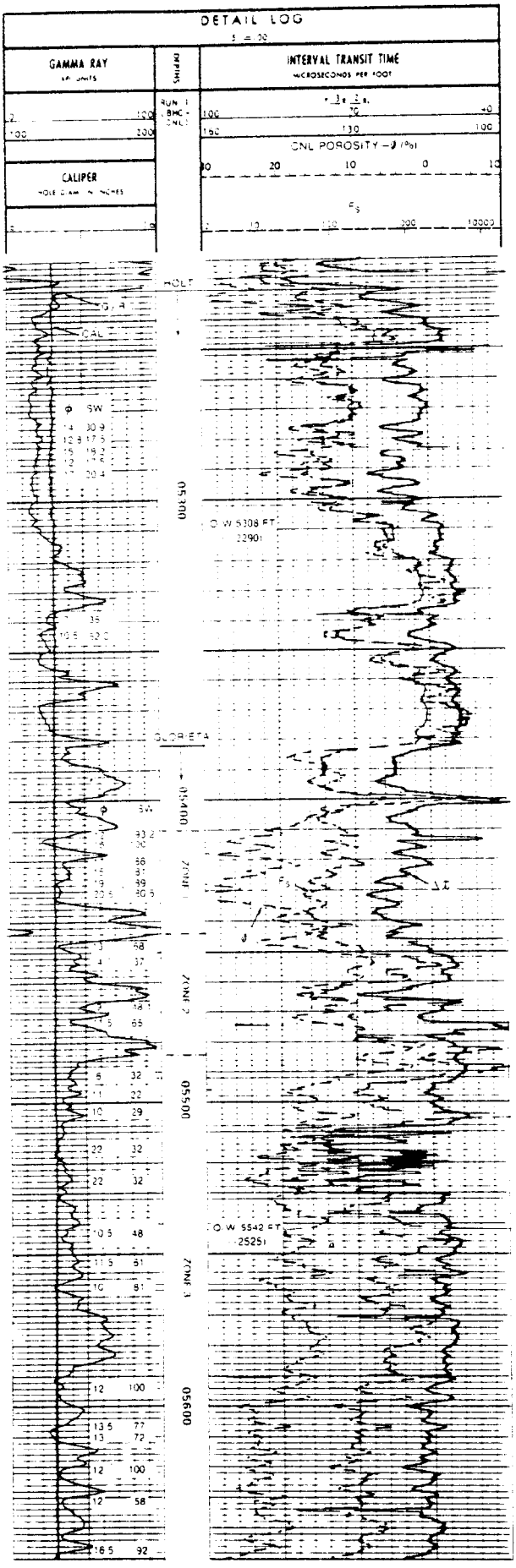

FIGURE 5—CROSS PLOT POROSITY AND WATER SATURATION THROUGH THE HOLT AND GLORIETA ZONES-JOHNSON DEEP UNIT NO. 1 WELL

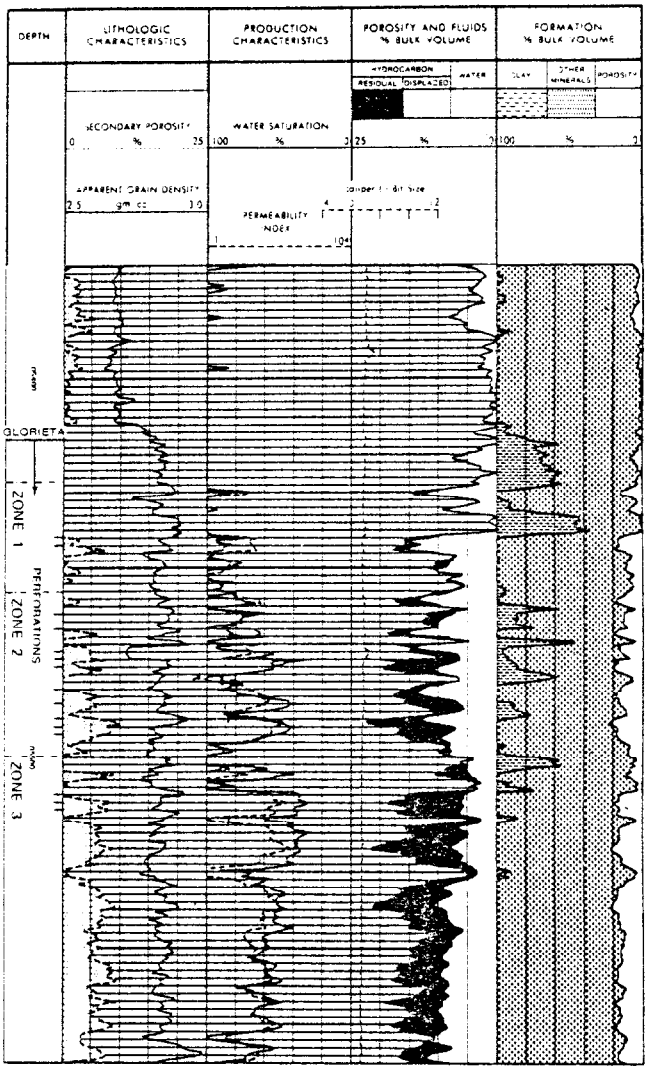

FIGURE 3—COMPUTER ANALYSIS BASED ON OPEN-HOLE LOGS, JOHNSON DEEP UNIT NO. 13 WELL

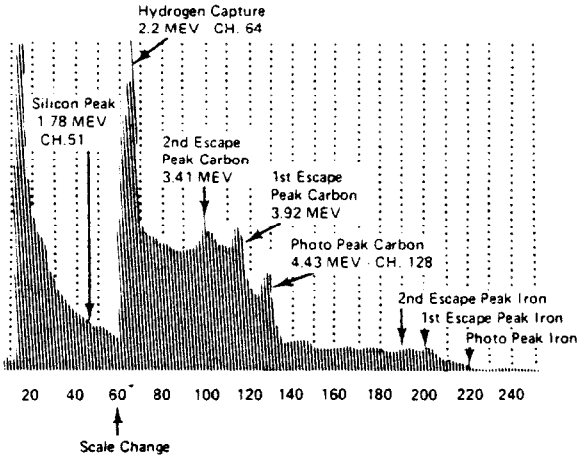

FIGURE 4—TYPICAL SURFACE CALIBRATION SPECTRUM OF THE CARBON/OXYGEN INSTRUMENT

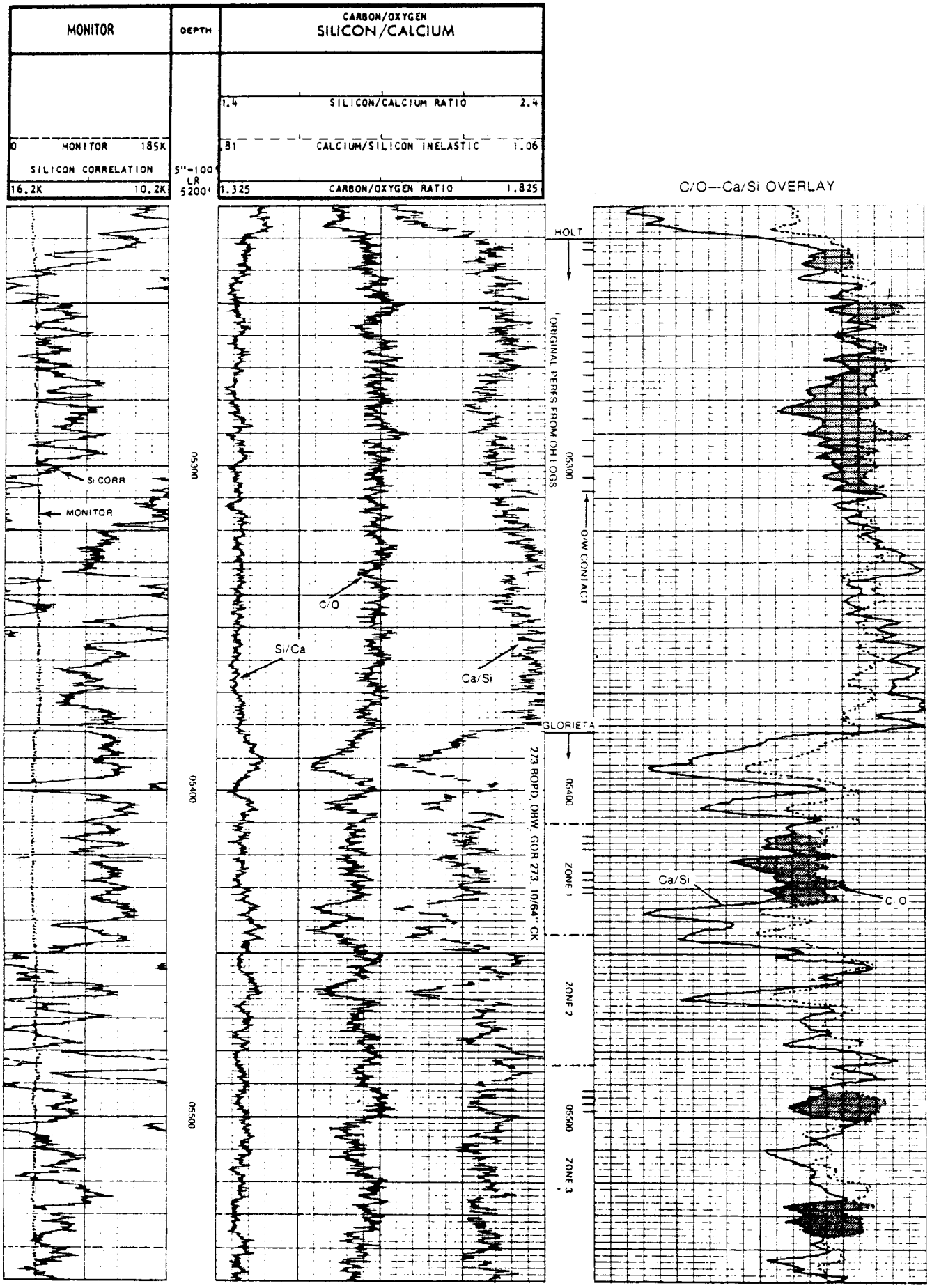

FIGURE 6—CARBON/OXYGEN LOG AND C/O - Ca/Si OVERLAY, JOHNSON DEEP UNIT NO. 1 WELL

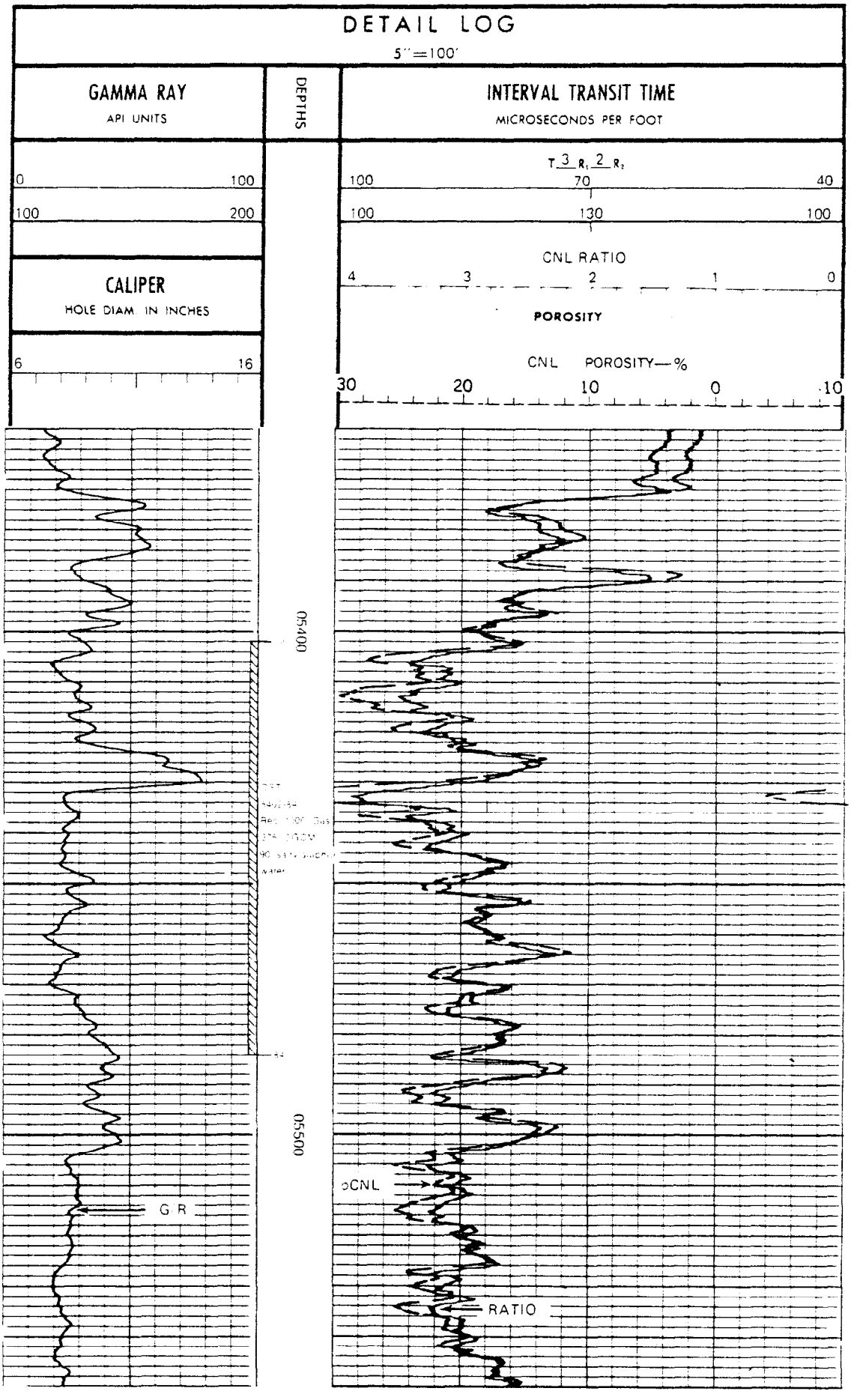

FIGURE 7—GLORIETA POROSITY LOG, JOHNSON DEEP UNIT NO. 2 WELL

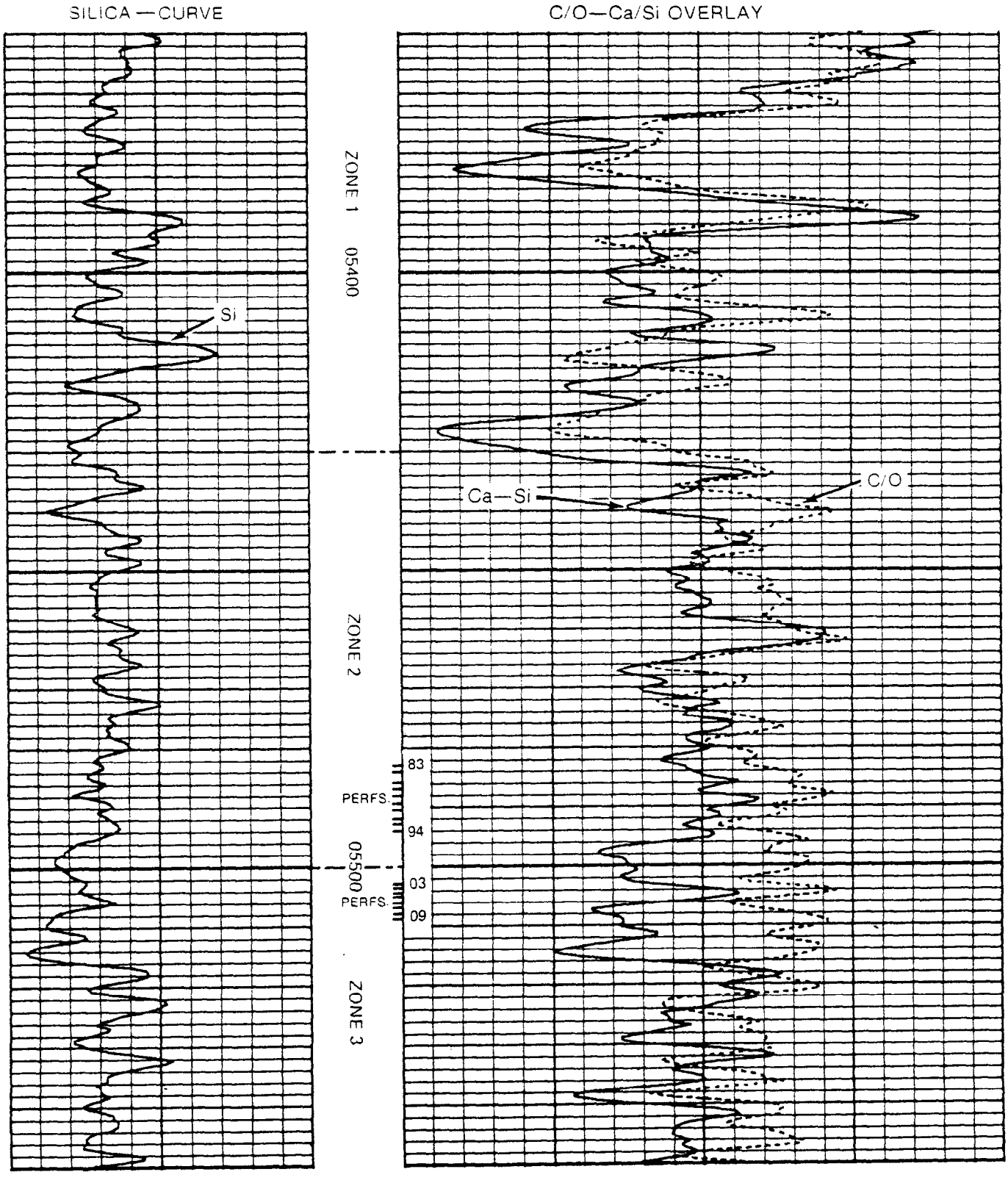

FIGURE 8—C/O · CA/Si OVERLAY SHOWING COMPLETION INTERVAL, JOHNSON DEEP UNIT NO. 2 WELL