U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

GEOPHYSICAL LOGGING OF CORED SECTION IN THE LONG VALLEY EXPLORATORY WELL, LONG VALLEY, CALIFORNIA

by

P. H. Nelson, J. Mikesell, and J. E. Kibler

Open File Report 92-544

Denver, Colorado
1992

GEOPHYSICAL LOGGING OF CORED SECTION IN THE LONG VALLEY EXPLORATORY WELL, LONG VALLEY, CALIFORNIA

P. H. Nelson, J. Mikesell, and J. E. Kibler
U.S. Geological Survey

INTRODUCTION

The USGS operates a slimhole logging system used for minerals, environmental, and scientific drilling projects. This system was used at Long Valley, California to log a cored hole extending from 6868 to 7588 feet which was wedged off from the rotary-drilled Long Valley Exploratory Well (LVEW; formally named Long Valley Federal 51-20). The USGS system was suitable because the tool diameters (1.8 to 2.3 inches) allowed operation within the 3.8-inch diameter cored hole. However, the hydrostatic pressures and temperatures encountered were greater than those on any previous projects to which the slimhole system had been applied.

The long-range drilling plan and scientific objectives for well LVEW are given by the Long Valley Science Panel (1991). The primary objective of well LVEW is "to test the hypothesis that juvenile magma is present below the caldera". Our logging work is part of Phase II of a planned four-phase drilling plan for well LVEW, which lies near the center of the resurgent dome within the Long Valley caldera. The western portion of the caldera is being explored as a potential source of geothermal energy. Geological, geophysical, and drilling operations have been underway for several years in an attempt to understand the nature of this young silicic volcanic system (Hill and Bailey, 1985; Goldstein and Stein, 1988; Sorey and others, 1991).

The well was rotary drilled to a depth of 7130 feet; excessive inclination caused the well to be plugged back (Finger and Jacobson, 1992). Open-hole logs were obtained by Schlumberger from 2556 to 6809 feet in September, 1991; the hole was then cased and an orienting wedge run into the hole. Core drilling through the wedge commenced at 6868 feet and continued to 7588 feet; coring operations terminated in November, 1991. A schematic of the casing and cement at the time of logging is shown in figure 1. Note that some of the logs obtained at the top of the cored section are likely to be affected by the proximity of the cemented hole. (In deference to logging and drilling practice, depths are reported in feet in this report.)

ACQUISITION

Logging commenced around 3 pm on August 9 and terminated about 5 pm on August 10, 1992. The depth reference point was the top of the Kelly bushing which was 30 feet above ground level. Bit size over the logged interval is HQ, about 3.85 inches diameter. Fluid level was above ground level in pipe making the hydrostatic pressure at 7588 feet about 3280 psi. All logs were acquired at a sampling density of five points per foot. The tools were lowered through drill pipe to a depth of about 6846 feet where they were diverted off a "window wedge" into the cored section of the hole (Finger and Jacobson, 1992). All probes were run without either a centralizer or a decentralizer. Temperature, pressure, and time constraints combined to limit the successful logging runs, as shown in the following table:

Tools successfully run	natural gamma-ray / thermal neutron electrical resistivity induced polarization
Tool failed during run	magnetic susceptibility (collapsed due to pressure)
Tools attempted but failed	caliper-fluid resistivity-temperature (failed due to temperature) sonic velocity (problem with uphole electronics)
Tools not attempted due to lack of time	density 3-axis magnetometer

Prior to logging, groundwater from a nearby well was circulated from the bottom of the cored section. In addition, two "viscous sweeps", or slugs of high-bentonite drilling mud, were pumped through to remove fragments of rubber material from previous hydrofrac operations (J. Finger, pers. comm., 1992). We assume that the borehole was filled primarily with water and with minor amounts of grease and polymer mud from drilling. We also assume that the circulated water quickly came to thermal equilibrium with the rock, attaining a temperature of about 100°C over the cored interval.

Normal resistivity and induced polarization logs were run with the same tool, eliminating the need for a trip to the surface to change the tool. The normal resistivity tool provides a single point resistance log and four normal (pole-pole) resistivity logs at spacings of 8, 16, 32, and 64 inches. At the end of this dual run, the cable had stretched 10 feet, that is, the depth counters read zero with the tool 10 feet below the Kelly bushing. Thus there is a depth uncertainty of 10 feet for these two runs. Subsequent runs produced a stretch of about 3 feet.

The induced polarization log was operated with a primary voltage electrode 16 inches above the current electrode. A surface mud-pit electrode could not be used as a reference due to rig-generated electrical noise, so an electrode 64 inches from the current electrode was used as a reference. Consequently, the spontaneous potential (SP) measurement was differential over a distance of 48 inches.

The magnetic susceptibility tool operated for about 150 feet into the cored section, then the fiberglass housing collapsed where it joined the stainless steel section, and the tool was irreparably damaged.

Several problems occurred with the combined caliper-fluid resistivity-temperature tool. The fluid resistivity sensor failed during descent within the casing when two insulating plastic pieces in the fluid resistivity sensor deformed and water invaded the sensor. The temperature sensor also failed, and temperature problems affected the caliper. No data were obtained with this tool.

No sonic velocity tool was obtained, due to several problems, including lack of a trigger pulse within the uphole module and apparent failure of the picker to lock on to the signal in one of the channels. After some time in the hole the uphole electronics locked up and could not be unlocked.

STRATIGRAPHY

The cored hole penetrates Paleozoic metasediments of the Mt. Morrison roof pendant. Information on stratigraphic picks and rubble zones from inspection of core are taken from McConnell and others (1992), which is understood to be preliminary. The core depths and stratigraphic picks are referenced to the Kelly bushing and are not corrected to ground level (V. McConnell, pers. comm., 1992).

DATA PROCESSING

All logs were first shifted so that the tool sensor aligned with the Kelley bushing reference. Inspection showed a disparity of 3 to 10 feet between most logs and the stratigraphic description. This disparity is probably due to a combination of elastic and inelastic cable stretch. Each log was individually shifted in depth to match the prominent geological boundaries found in core, most particularly with the boundaries of the thick metaquartzites.

The gamma-ray log was observed to increase steadily with depth during the down-going logging run. A second upgoing run was made and counts continued to increase as depth decreased (figure 2). We interpret this effect as due to the continually increasing temperature of the photomultiplier tube (heating of the dynodes within the tube is quite slow because they are in vacuum). As heating occurs, all pulse heights increase and consequently low amplitude gamma-ray pulses below the discriminator setting begin to be counted, raising the counting rate. With the addition of the low-level pulses, statistical (Poisson) noise increases and tends to mask the features of the natural gamma-ray signature in the upgoing trace. To compensate for this progressive heating effect, a "ramp" was removed from the downgoing gamma-ray log with two linear fits. As a result, the gamma-ray log is presented unscaled and trends in the log over distances exceeding roughly 100 feet are not reliable. Finally, a seven-point triangular smoothing filter was applied to the gamma-ray logs to reduce statistical noise.

To accomodate an exceptionally large dynamic range in resistivity values (about four decades) found in this hole, four runs were made at different current settings. All detail at high resistivity values was captured, but both offset and noise are present at low resistivity values of one ohm-m and less. Because the signal-to-noise ratio was lowest at the higher spacings, the 32 and 64-inch traces were eliminated from the data set and the 8 and 16-inch traces were retained. At the most sensitive (highest current) setting, one millivolt corresponds to 0.5 ohm-m, which is about the uncertainty in terms of offset and noise for the 16-inch trace. After close inspection of the log, an offset of 0.4 millivolt was added to the 8-inch trace and 0.8 mV was subtracted from the 16-inch trace. These changes produced consistent traces at 1.0 ohm-m and less, but the user must be aware that values less than 1.0 ohm-m are somewhat uncertain, so that within the conductive zones, the log serves primarily to delineate bed boundaries. As values increase above 1.0 ohm, the uncertainty due to offset becomes negligible.

A value of 6.6 ohm-m at 25°C was measured for the water used to circulate the hole (J. Finger, pers. comm., 1992); this converts to about 2.2 ohm-m at 100°C. Iterative calculations indicated that this value was reasonable for Rm, and calculations were done to remove the borehole (mud) effect. Finally, to overcome the dynamic range problem, the final 8 and 16-inch resistivity traces were composited from three runs done at different current settings.

DISCUSSION

The induction log acquired by Schlumberger (figure 3) shows that resistivity declines precipitously from the 10 ohm-m level to values of one ohm-m and lower at 6648 feet (2027 m), the contact between the volcanic tuff and the metasediments. Our normal resistivity measurements (R08 and R16 on figure 4) show that resistivity values remain at one ohm-m and less throughout much of the 700-foot cored section commencing at 6868 feet. These exceptionally low resistivity values are associated with carbonaceous (graphitic?) material in the hornfels.

A three-dimensional electrical model based upon magnetotelluric and other electrical surveys by Park and Torres-Verdin (1988) shows a large (8 x 16 km) conductive unit of less than one ohm-m at a depth of 1350 to 1600 m. Well LVEW lies within a southern tongue of their conductive unit, close to a lateral boundary with a resistive (>500 ohm-m) unit. They cite (Table 2 of Park and Torres-Verdin, 1988) values of 1 to 25 ohm-m for the metasediments encountered in well M-1 which lies south of well LVEW. They believe that "this conductor is graphitic metasediment beneath the floor of the caldera".

A two-dimensional electrical model based upon a more recent magnetotelluric east-west profile across Long Valley also indicates a conductive unit of less than 10 ohm-m (Wannamaker and others, 1991, figure 11). The conductive unit in their model extends from a depth of 1500 to 2000 m. Well LVEW lies very close to their magnetotelluric profile.

The electrical data from well LVEW substantiates the belief that the metasediments are quite conductive and are likely to be the cause of the conductive units modelled by both Parks and Torres-Verdin (1988) and by Wannamaker and others (1991). However, the depth of 2027 m to the metasediments in well LVEW is at or below the bottom of the conductive units as interpreted from the magnetotelluric data. Wellbore inclination is so slight that true depths are about two feet shallower than actual depths (Finger and Jacobson, 1992, figure 2). Thus, a substantial discrepancy between the logs and the model depths remains to be resolved.

Resistivity is high, often greater than 100 ohm-m, in the metaquartzite, marble, and argillite. Resistivity also reveals changes within the hornfels. Above 7250 feet, resistivity values in the hornfels are 1 ohm-m or less. From 7250 feet to 7285 feet a ramp-like increase in resistivity occurs, and below 7285 feet values in the hornfels exceed 1 ohm-m. It is likely that quantity or habit of the carbonaceous material is different above and below 7250 feet.

From 7400 to 7415 feet a resistive zone occurs within the hornfels. The geologic log indicates that the bands of light and dark color in the hornfels disappear within this interval.

In addition to the 8-inch and 16-inch resistivity logs, a single point log (RPT) is also shown on two linear scales in figure 4. The single point resistance is the voltage to current ratio of the lowermost current electrode on the resistivity tool. Overall, RPT mimics the R08 and R16 curves, but it provides a higher spatial resolution than the 8-inch resistivity log. Where the resistivity is low, a backup single point resistance curve, labelled RPT_EX, is provided on an expanded scale to bring out the electrical structure within the conductive hornfels units. Where the resistivity is high, and the resolution of the RPT curve is adequate, the RPT_EX curve is nulled. As an example of the usefulness of the RPT_EX curve, several resistive features with an apparent thickness of a foot or less are shown between 6900 and 6920 feet. Light and dark colored bands with individual thickness on the order of centimeters and less are visible in the hornfels (V. McConnell, pers. comm. 1992). It is unlikely that these resistive spikes reflect individual bands because they are too thin and are inclined to the borehole at an angle of 55°.

We were unable to find any reliable correlation of the logs with the rubble zones (designation for fragmented core) noted in the core description and shown in track 1 of figure 4. There was no change in porosity indicated by the neutron log in the rubble zones. A sonic velocity log would have been the best indicator of fractured zones, but it was not run.

Neither the IP nor the SP contribute to lithology identification, although the IP does respond to the metaquartzites (figure 4). The negative-going swings on the IP at the thick resistive metaquartzite intervals suggest a possible problem with tool response; there was no evidence otherwise that the tool was malfunctioning. The discrete positive spikes may be related to concentrations of pyrite and this should be checked against core. As mentioned above, the SP log is actually a differential SP, and needs further processing before it can be interpreted as an SP log. The magnetic susceptibility log, which terminates at 7004 feet due to tool failure, indicates that suceptibility in the hornfels is generally quite low indicating a lack of magnetic minerals such as magnetite.

The gamma-ray log produces low counts in the metaquartzites and in some, but not all, marbles. Within the hornfels, the gamma-ray count rate is fairly constant.

The neutron log is scaled in apparent porosity units. The exponential decrease in apparent porosity at the top of the log (6862-6890 feet) is attributed to the proximity of cement, which is high in bound water, in the nearby rotary-drilled wellbore. The following features of geological interest can be observed in the neutron log:

a) very low (zero) apparent porosity in metaquartzite.
b) very high (20%) apparent porosity in marble.
c) apparent porosity values ranging from 3% to 13% in hornfels.
d) apparent porosity increasing with depth in hornfels.

Three common chemical elements cause changes in thermal neutron response: hydrogen because of its ability both to slow (thermalize) the neutron flux and to capture thermal neutrons, and chlorine and iron because of their relatively high capture cross-section for thermal neutrons. At the detector spacing used in our tool, high neutron flux corresponds to low hydrogen concentration and low chlorine and iron content. The exceptionally low (near zero) apparent porosity (high neutron flux) observed in the metaquartzite indicates very low true porosity, the absence of clays (bound water), and the absence of any major (chlorine, iron) or trace (boron, gadolinium) elements that could capture neutrons.

It is likely that porosity is low (less than 5%) throughout the metasediments, so the high apparent porosity response of 25% in the marble and of 10 to 15% in the hornfels at depths greater than 7360 feet (figure 4) must be explained by some means other than water in pore space. In the deeper hornfels units, the best candidates are hydrogen-bearing micaceous minerals such as biotite, and iron-bearing minerals such as pyrite and biotite. In the marble the best candidates are pyrite and possibly iron substituting for calcium and magnesium in the calcite structure.

Because the thermal neutron log shows high apparent porosity in marble and low apparent porosity in metaquartzite, it is an excellent discriminator between marble and metaquartzite (figure 4). Neither the electrical resistivity, which is high in both marble and metaquartzite, nor the gamma-ray activity, which is reduced in both metaquartzite and marble, can discriminate between the two. Note the example at 6960 feet where metaquartzite overlays marble; the resistivity and gamma traces delineate the metaquartzite and the neutron log delineates the marble.

SUMMARY

Electrical resistivity, thermal neutron, gamma ray, and induced polarization logs were obtained in the cored section of the Long Valley Exploratory Well. Resistivity is quite low (one ohm-m and less) in much of the hornfels, and high (100 to 1000 ohm-m) in the marble and metaquartzites. The neutron log readily discriminates between marble and metaquartzite. These simple relationships can be exploited when examining the core, and future core and thin section description will help explain other features in the geophysical logs.

REFERENCES

Finger, J.T. and R.D. Jacobson, 1992, Phase II drilling operations at the Long Valley Exploratory Well (LVF 51-20), Sandia Report SAND92-0531, Sandia National Laboratories, 114 p.

Goldstein, N.E. and R.S. Stein, 1988, What's new at Long Valley, J. Geophysical Res., v. 93, n. B11, p. 13,187-13,190, Nov. 10.

Hill, D.P. and R.A. Bailey, 1985, Active tectonic and magmatic processes beneath Long Valley caldera, Eastern California: an overview, J. Geophysical Res., v. 90, n. B13, p. 11,111-11,120, Nov. 10.

Long Valley Science Panel, 1991, Investigation of active volcanic processes in Long Valley Caldera via deep continental drilling, Lawrence Livermore Natl. Lab., UCRL-PROP-108826, 31 p.

McConnell, V.S., J.C. Eichelberger, M.J. Keskinen, and P.W. Layer, 1992, Geologic results from the Long Valley Exploratory Well, Proc. of the Geothermal Program Review X, p. 129-134.

Park, S.K. and C. Torres-Verdin, 1988, A systematic approach to the interpretation of magnetotelluric data in volcanic environments with applications to the quest for magma in Long Valley, California, J. of Geophysical Res., vol. 93, no. B11, p. 13,265-13,283, Nov.

Sorey, M.L., G.A. Suemnicht, N.C. Sturchio, and G.A. Nordquist, 1991, New evidence on the hydrothermal system in Long Valley caldera, California, from wells, fluid sampling, electrical geophysics, and age determinations of hot-spring deposits, J. Volc. and Geothermal Res., v. 48, p. 229-263.

Wannamaker, P.E., P.M. Wright, Z. Zi-xing, L. Xing-bin, and Z. Jing-xiang, 1991, Magnetotelluric transect of Long Valley caldera: resistivity cross-section, structural implications, and the limits of a 2-D analysis, Geophysics, vol. 56, no. 7, p. 926-940, July.

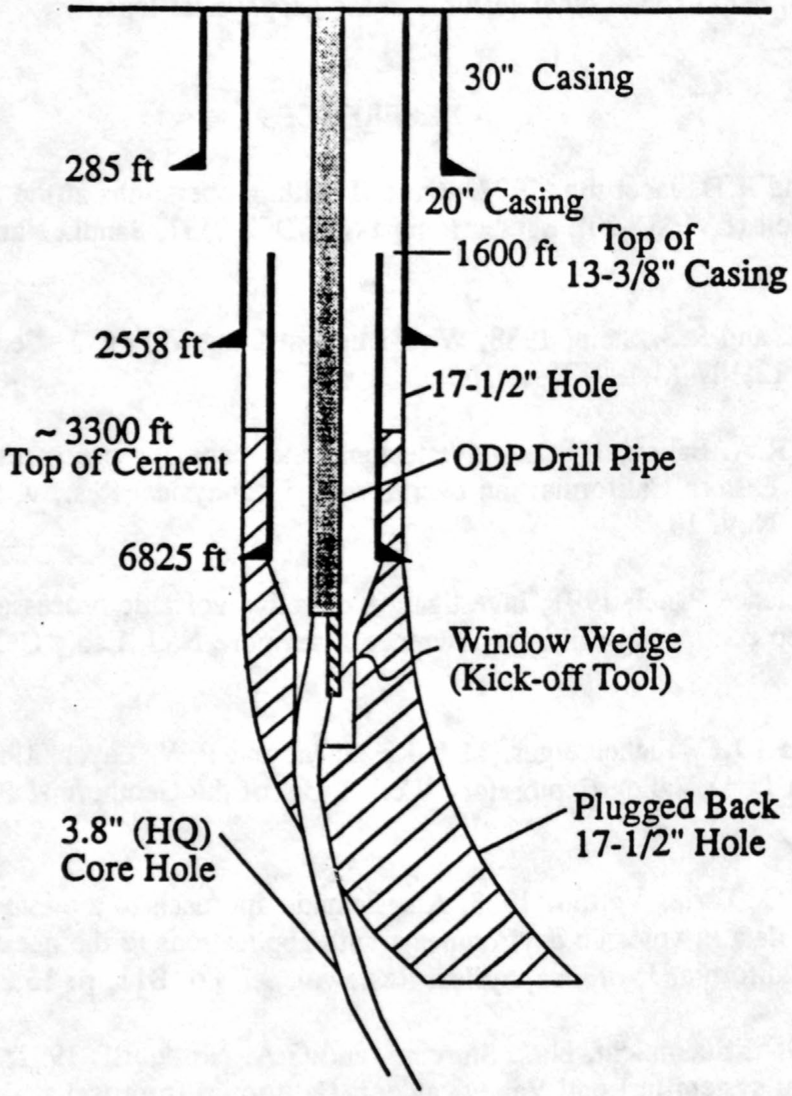

Figure 1. Schematic of casing in Long Valley Exploratory Well, from Finger and Jaocbson (1992). Logged section discussed in this report extends from 6868-7578 feet in the cored hole. The drawing is highly schematic; the actual angle between the core hole and the plugged hole is about 1.5 degrees.

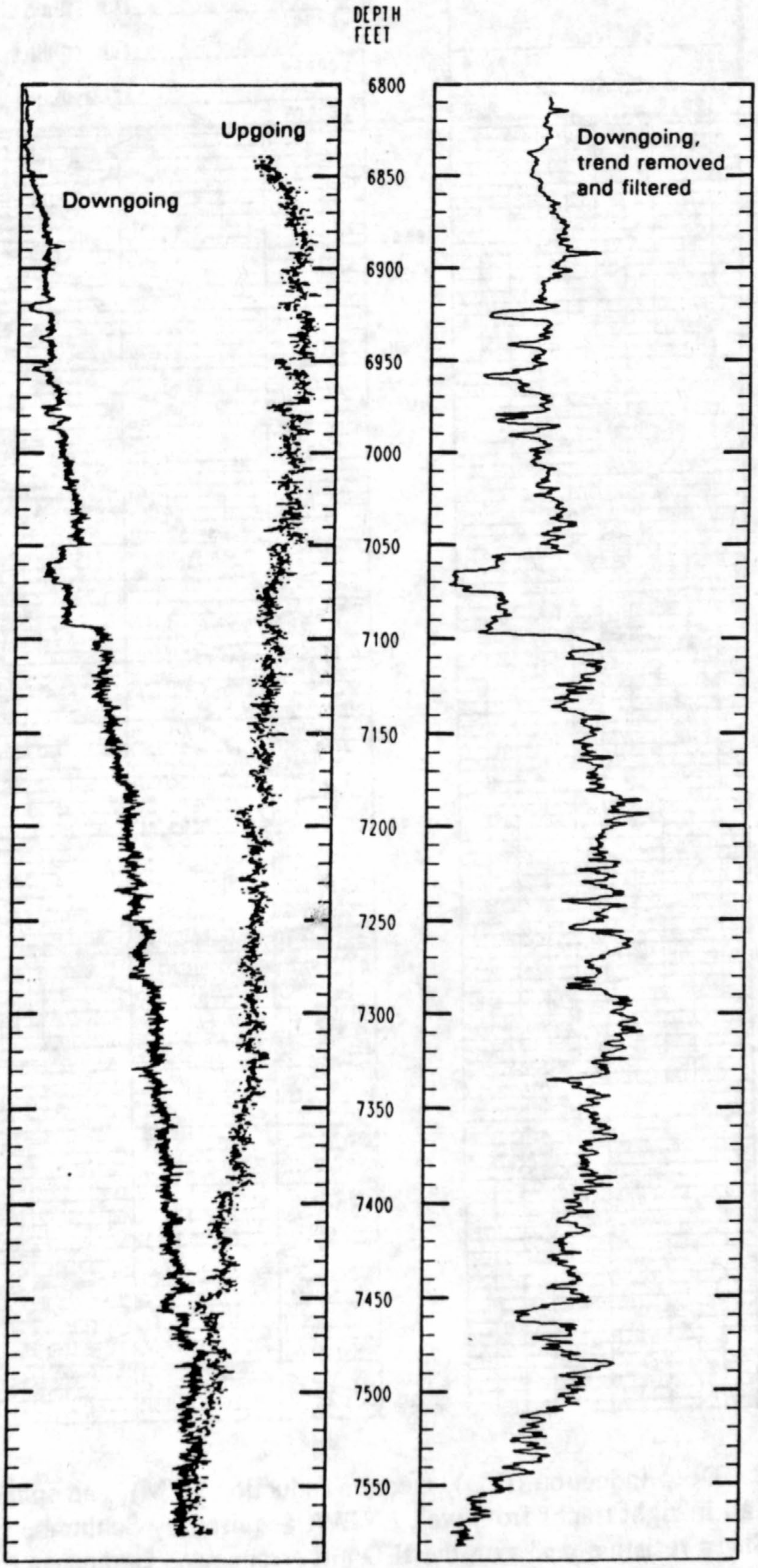

Figure 2. Downgoing and upgoing gamma-ray logs (left track) showing thermal drift, and in the right track, a log extracted from the downgoing log by removal of linear trends. The extracted log has also been filtered.

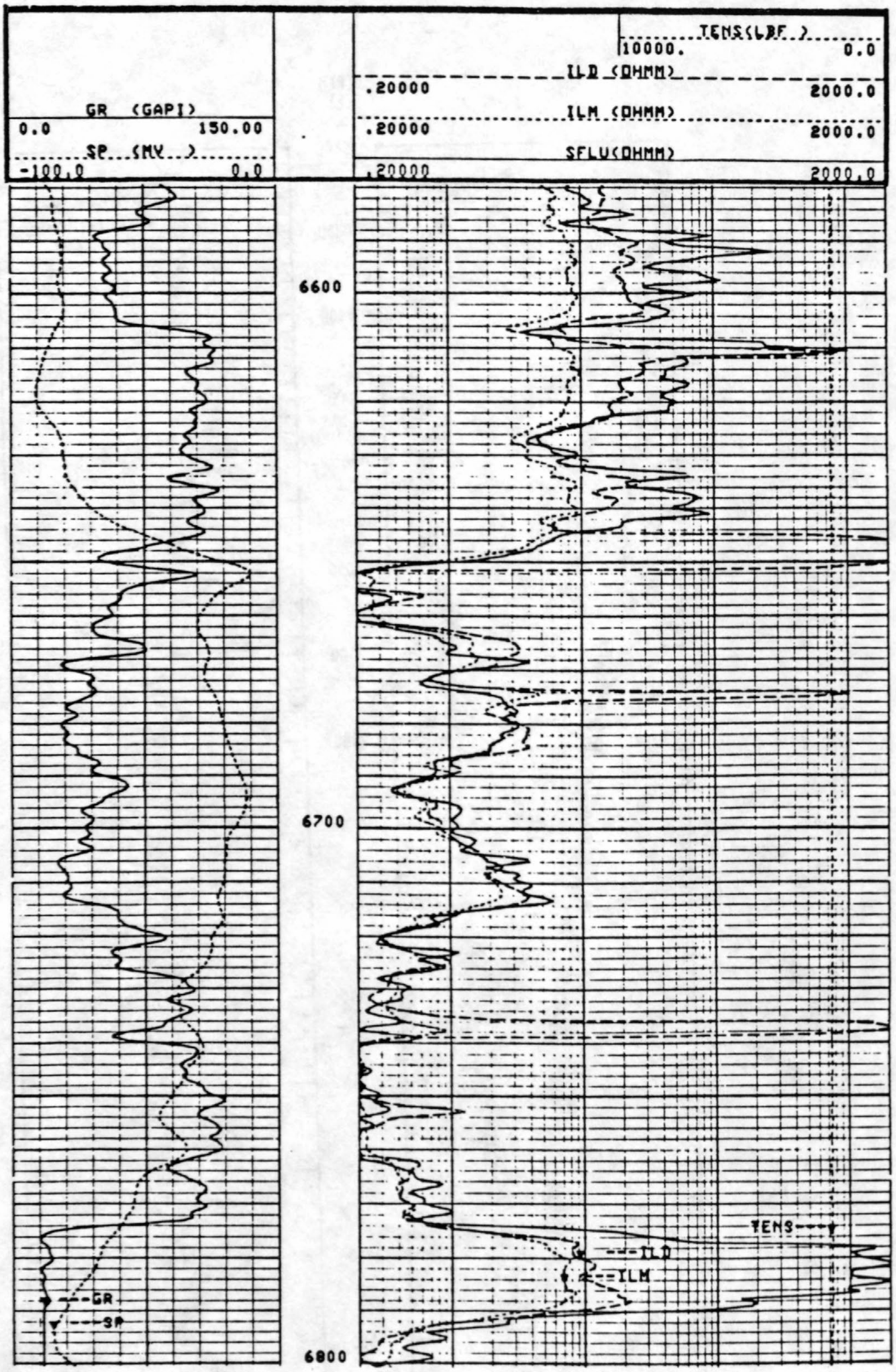

Figure 3. Deep induction (ILD), medium induction (ILM), and spherically focussed logs (SFLU, all in right track) from well LVEW, acquired by Schlumberger on 13 September 1991. Sharp resistive peaks on the ILD are erroneous. Gamma-ray (GR) and SP logs are shown in the left track. Transition from overlying volcanic tuff to Paleozoic metasediments occurs at 6648 feet.

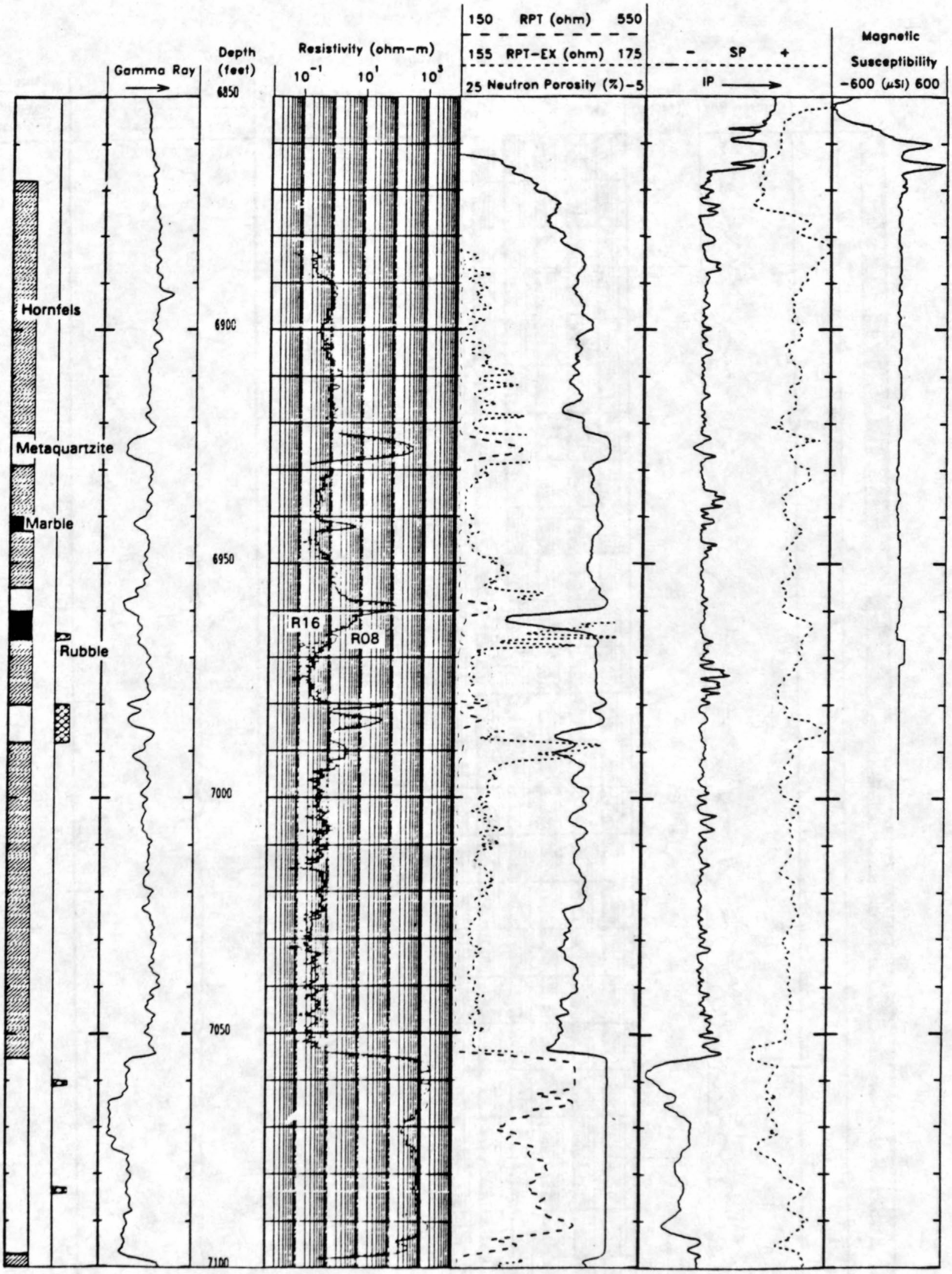

Figure 4. Stratigraphy and core condition, track 1, from McConnell and others (1992); gamma ray (no scale), track 2; 8-inch (R08) and 16-inch (R16) normal resistivity, track 3; neutron porosity, single point resistance (RPT) and expanded single point resistance (RPT-EX) in track 4; induced polarization (IP) and spontaneous potential (SP) in track 5; magnetic susceptibility, track 6.

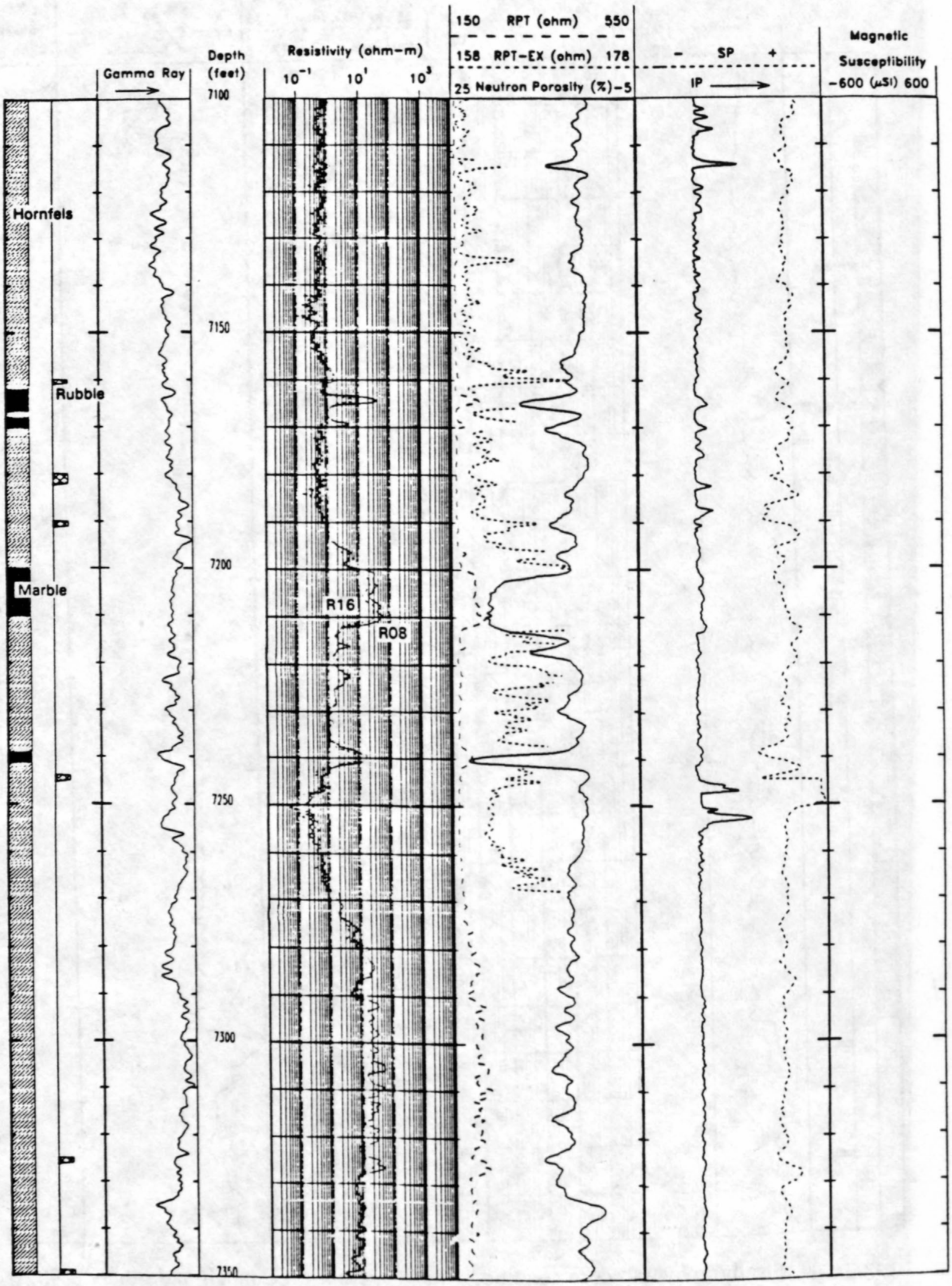

Figure 4, continued.

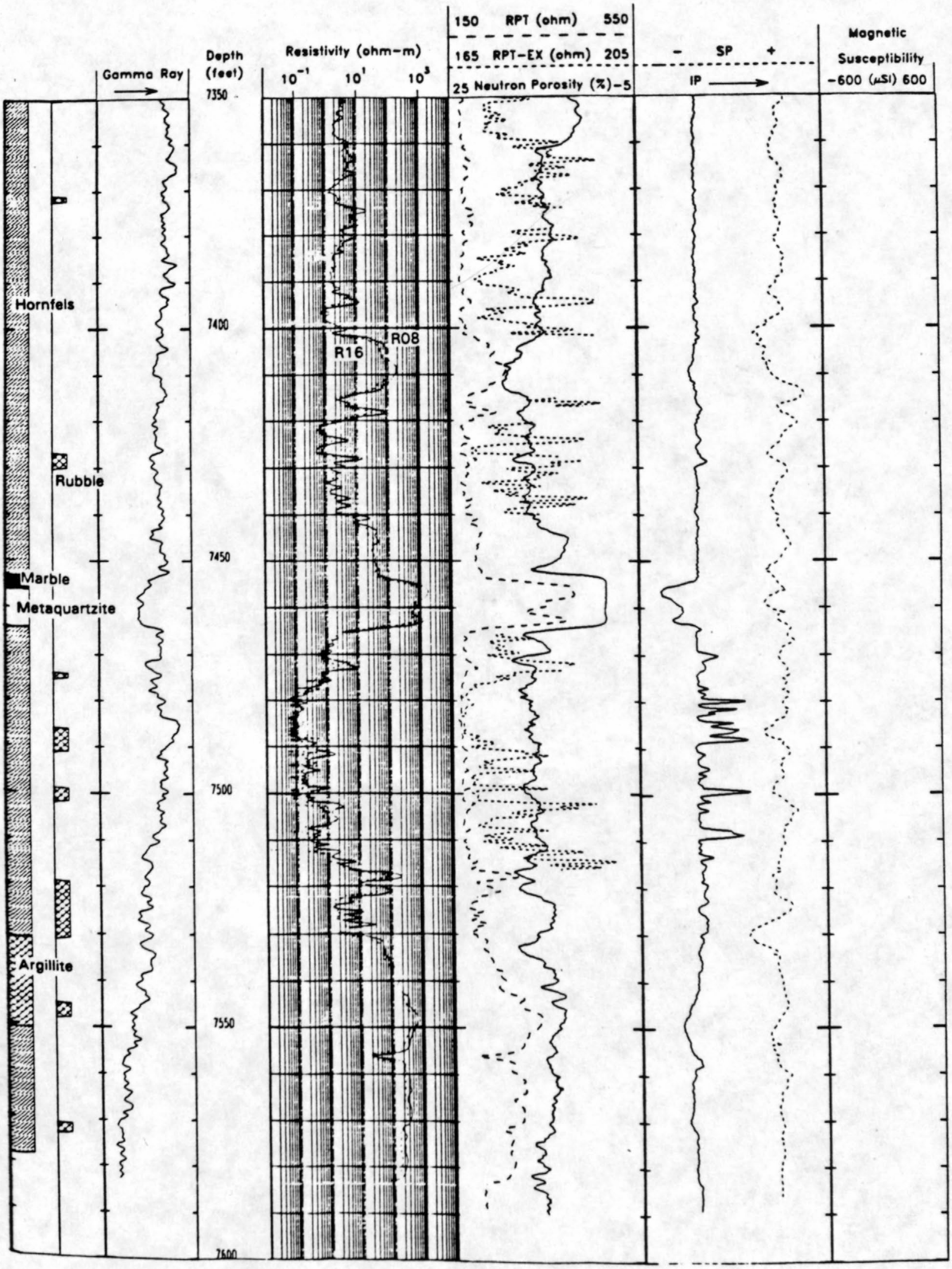

Figure 4, continued.