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APPLICATION OF GEOPHYSICAL LOGS TO ESTIMATE MOISTURE-CONTENT PROFILES IN UNSATURATED TUFF, YUCCCA MOUNTAIN, NEVADA

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Abstract

Determination of the moisture content in boreholes, drilled for the purpose of conducting hydrological studies in the unsaturated zone, is critical in the evaluation of the natural state of the unsaturated zone. Geophysical logs combined with geologic and hydrologic examination of the borehole cuttings provide a means to estimate moisture-content profiles. Interpretations of geophysical well logs for unsaturated, welded, and fractured tuff have not been attempted previously. This paper compares the results of analyses of various geophysical logs that were obtained from two large diameter, air-drilled (vacuum reverse circulation) boreholes at Yucca Mountain, Nevada, that were drilled as part of the Nevada Nuclear Waste Storage Investigations Project of the U.S. Department of Energy.

Caliper, gamma-ray, temperature, induction, density, epithermal-neutron, and dielectric logs were run in these boreholes. Moisture-content data from the drill cuttings were compared with moisture-content data derived from logs. Saturation profiles were obtained from different logs and were correlated with each other. Qualitative correlation of the degree of welding with bulk density al[...] was conducted; overall correlations were satisfactory. Borehole geophysical logs proved reliable in determining moisture-content profiles.

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Introduction

This investigation is part of the Nevada Nuclear Waste Storage Investigations (NNWSI) Project. It is conducted in cooperation with the U.S. Department of Energy, Nevada Operations Office, under Interagency Agreement DE-AI08-78ET44802.

Boreholes USW UZ-1 and USW UZ-6 were drilled at Yucca Mountain, Nevada, for the purpose of studying the unsaturated zone. They were drilled with a 17.5-inch (44.45-centimeter) bit size; however, hole size, particularly in borehole USW UZ-6, was much larger than bit size along most of the borehole, (Whitfield, 1985, this proceedings). Both of these boreholes were drilled without the use of drilling fluid. Drill cuttings were removed from the well by air (vacuum reverse circulation) so that drilling fluid would not disturb the original moisture content of the rocks. This study was made to determine if geophysical well logs qualitatively can be correlated with moisture profiles derived from drill cuttings from the unsaturated zone and to determine if geophysical well logs are useful for determining various rock properties even when borehole conditions are not optimum.

Available logs

<u>Caliper</u>: Included to give a clearer picture of the borehole size variations.

<u>Gamma-ray</u>: Not used for interpretation, but useful for determining some of the boundaries of the formations.

<u>Temperature</u>: Not included because it was not giving good anomaly over the moisture zones, possibly because the borehole was too large. A differential-temperature log, rather than a gradient-temperature log, would have been more helpful, despite the large borehole size.

<u>Induction</u>: Very good in locating the moisture zones. Data had excellent contrast; resistivities were 10 to 50 ohm-m for moisture zones and 90 to 220 ohm-m for dry zones. This log is included and is used to support the moisture-content profile derived from the dielectric log.

Density: Used to determine porosities. Matrix densities required for porosity calculations were obtained from drill cuttings. Bulk densities also were qualitatively correlated with the degree of welding.

Dielectric: Used to determine the moisture-content profiles directly by using the formula of Geng et al. (1983). Various dielectric cementation factors were tested for calculations; the resultant moisture-content profiles were satisfactory.

Epithermal-neutron: Used for qualitative correlation with moisture profiles; very useful for locating moisture zones.

Interpretation of Logs

Caliper logs from boreholes USW UZ-1 and USW UZ-6 are shown in Figures 1A and 1B, respectively. Both of these boreholes had abrupt variations in the borehole sizes.

Water-saturation Calculations and Comparisons

An attempt was made to calculate porosities from density logs. Matrix-density values were obtained from drill cuttings. Porosities were calculated by the following formula:

$$\phi = \frac{dm - db}{dm - df} \qquad (1)$$

where

ϕ = porosity,
dm = matrix density, gr/cm^3,
db = bulk density, gr/cm^3, and
df = fluid density, gr/cm^3.

As shown in Figure 2 for borehole USW UZ-1, and in Figure 3 for borehole USW UZ-6, density logs, calculated porosities, and degree of welding, which were determined from cores, samples, etc., correlated very well. As expected, porosities calculated from density logs were greater than porosities determined from core analysis. This difference was caused by the effect of partial gas saturation on bulk-density measurements. Before saturation calculations were made, it was necessary to know the formation-water resistivity. Resistivity logs of a nearby borehole drilled by conventional methods, USW H-1, were used

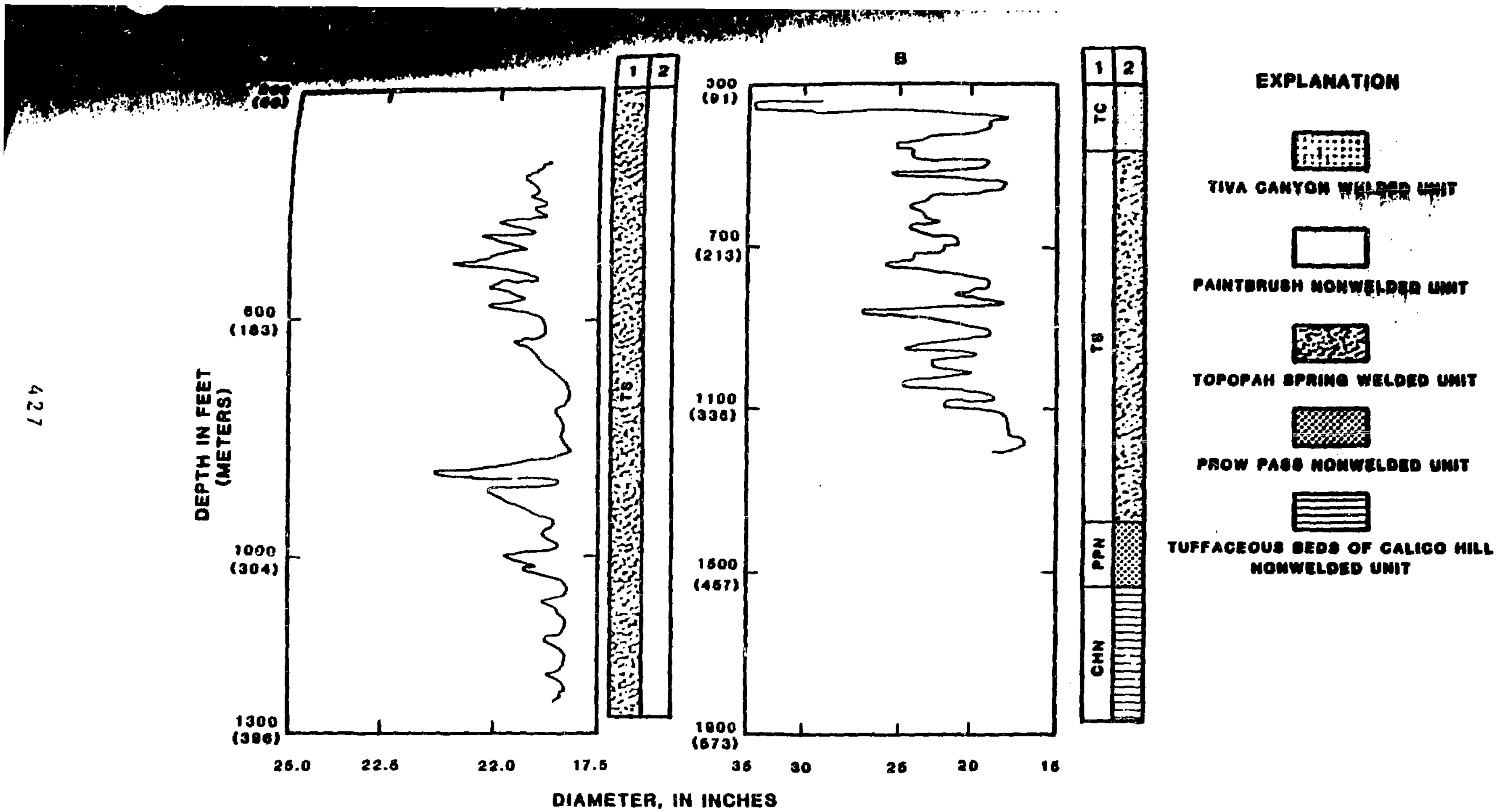


Figure 1. Caliper logs--(A) borehole USW UZ-1, and (B) borehole USW UZ-6--showing the borehole-diameter variation. Drill-bit size for both boreholes is 17.5 inches (44.45 centimeters).

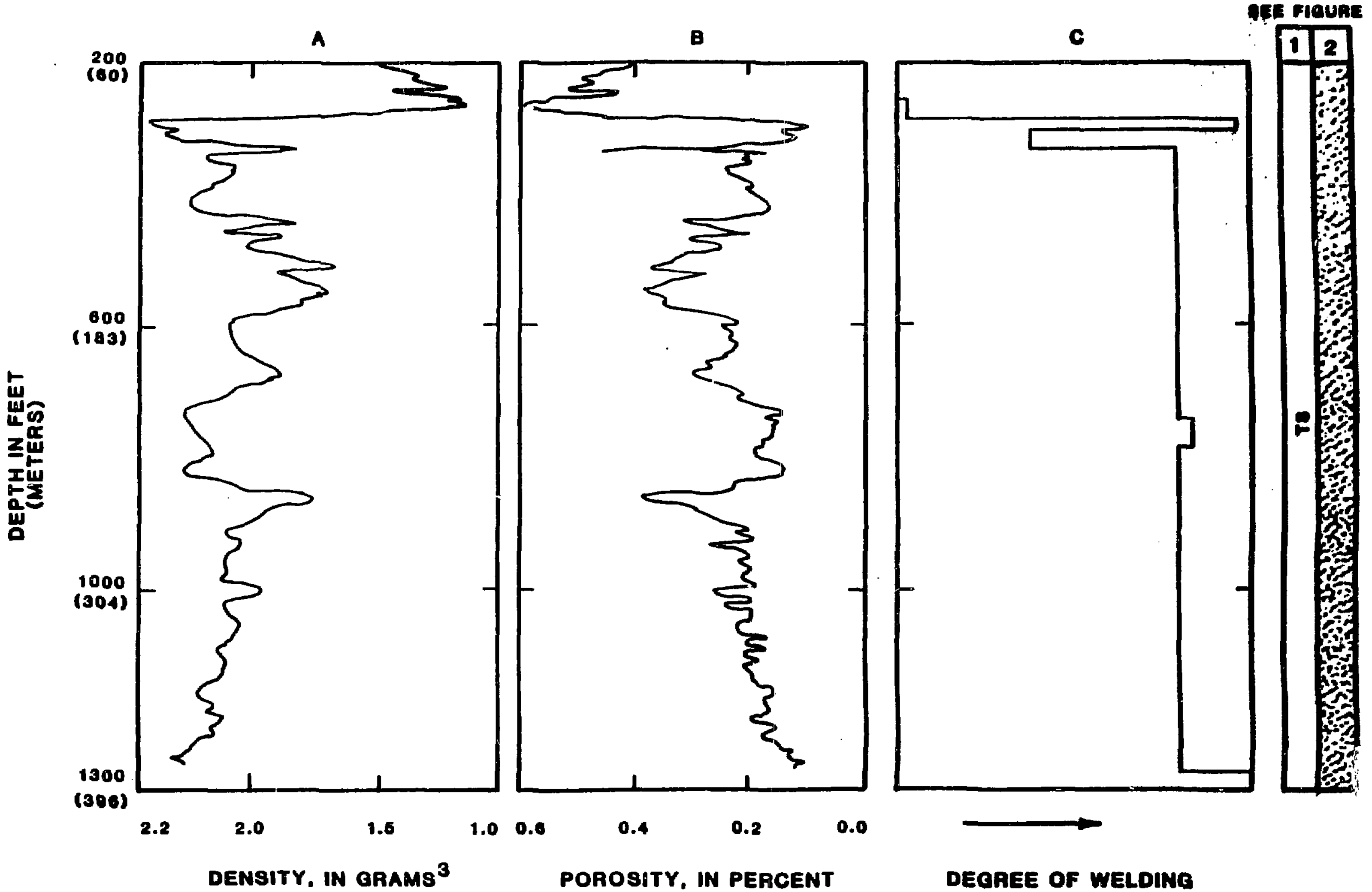


Figure 2. Borehole USW UZ-1--(A) density, (B) porosity derived from density, and (C) degree of welding determined from core and drill cuttings.

Figure 2. Borehole USW UZ-1--(A) density, (B) porosity ... degree of welding determined from core ... drill cuttings.

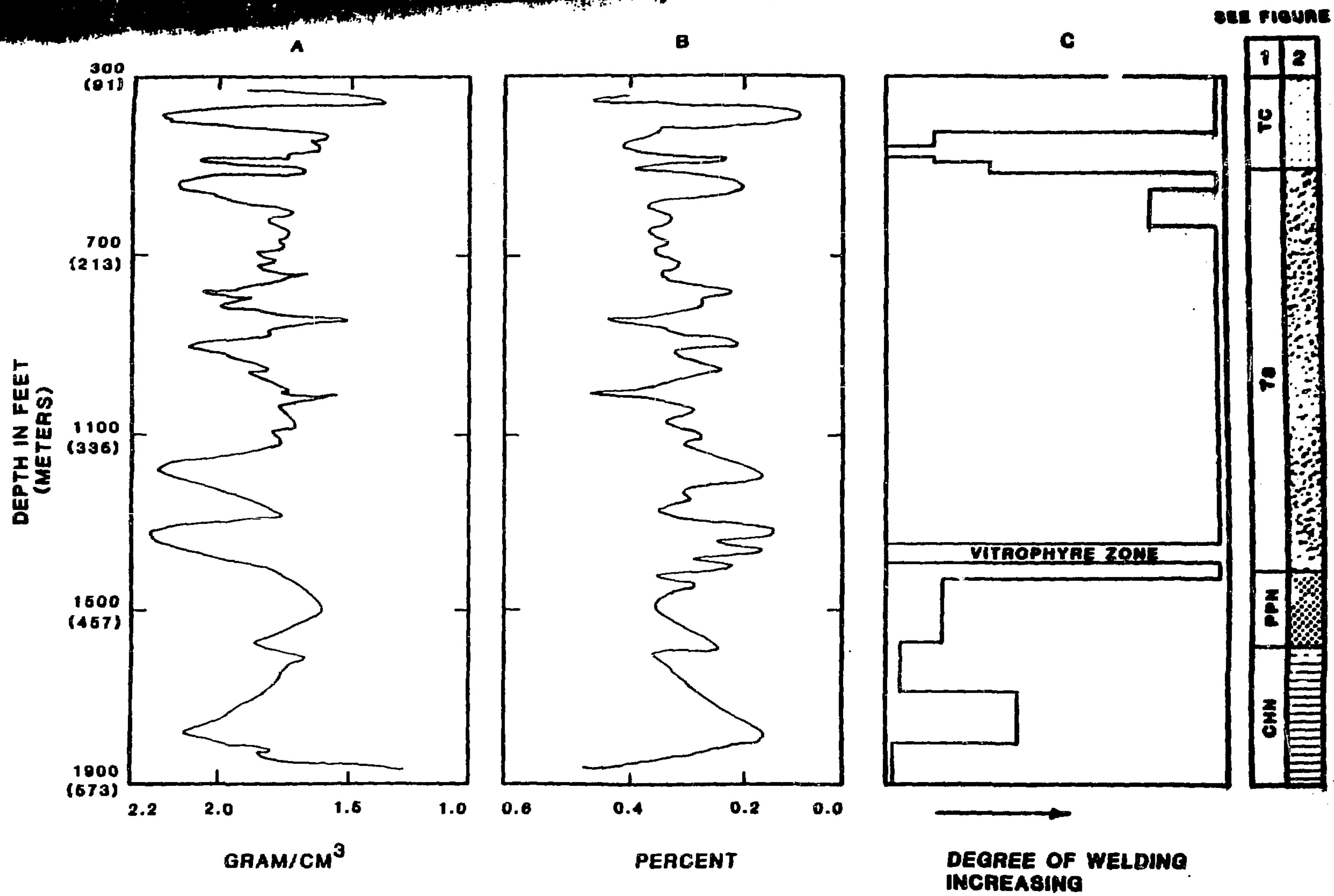


Figure 3. Borehole USW UZ-6--(A) density, (B) porosity derived from density, and (C) degree of welding determined from core and drill cuttings.

for calculating formation-water resistivity. Water-saturation values then were calculated by using the following equation:

$$S_w^n = (R_w/R_t)\ 1/\phi^m\ ;\ m = n = 2.0 \qquad (2)$$

where

S_w = water saturation,
ϕ = porosity,
R_w = resistivity of fluid in the rock, ohm-m²/m,
R_t = true resistivity of the rock, ohm-m²/m,
m = cementation constant, and
n = saturation exponent.

It was determined, after testing varying m and n values for different intervals, that water-saturation values did not vary much. Then m and n values were set as 2.0 along the borehole. Water-saturation values also were calculated after taking porosities from the density log and using the moisture-content profile derived from the dielectric log:

Water saturation = moisture content/porosity.

This saturation profile was compared with the curve determined previously, and the correlation was considered satisfactory. The correlation between water-saturation values derived from formation resistivity and porosity (A) and dielectric constant and porosity (B) is shown in Figure 4 for borehole USW UZ-1, and in Figure 5 for borehole USW UZ-6.

Moisture-content Calculations and Comparisons

Moisture content was calculated by using dielectric-constant values from the dielectric logs. The empirical equation from Geng et al. (1983) was modified, and the volumetric friction of shale was set equal to zero with an assumption that there was not much contribution from clay minerals at this site to the dielectric-constant values. The modified equation is:

$$\Sigma^c = 1.67 + (2.44\ S_{wv} - 0.39) + 1.77\ V_{sh} \qquad (3)$$

where

Σ is dielectric constant readings from log,
c is dielectric cementation factor,
S_{wv} is moisture content of tuff, and
V_{sh} is volumetric friction of shale in the tuff.

For volcanic tuff, the dielectric cementation factor, c, was unknown. Various c values were used for borehole USW UZ-1, and moisture-content values were determined. Comparison of the moisture-content profile from drill cuttings with the calculated moisture-content profile was very unrealistic when the calculations were made using a dielectric

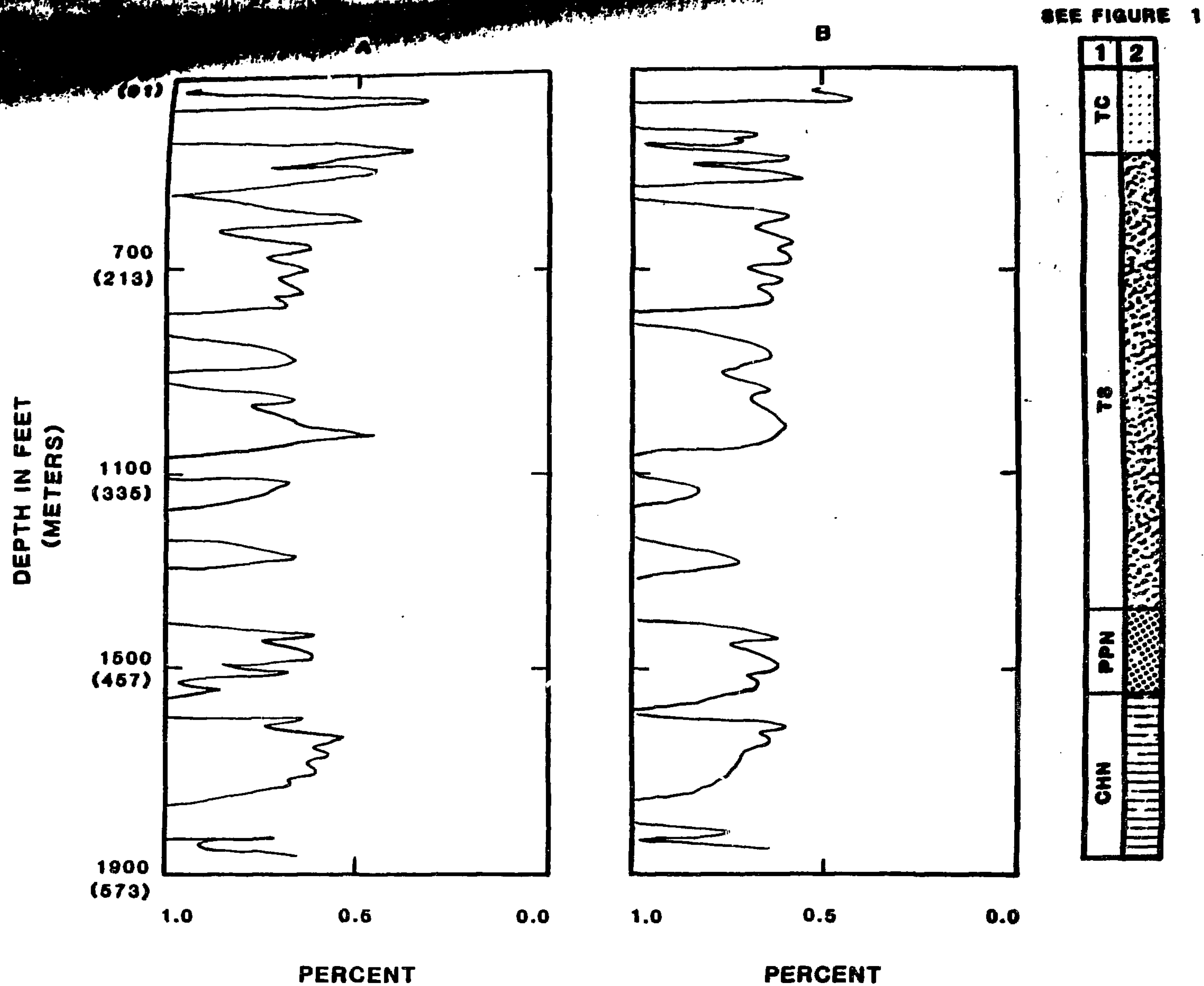


Figure 4. Borehole USW UZ-1, water saturation derived from--(A) formation resistivity and porosity, and (B) dielectric constant and porosity.

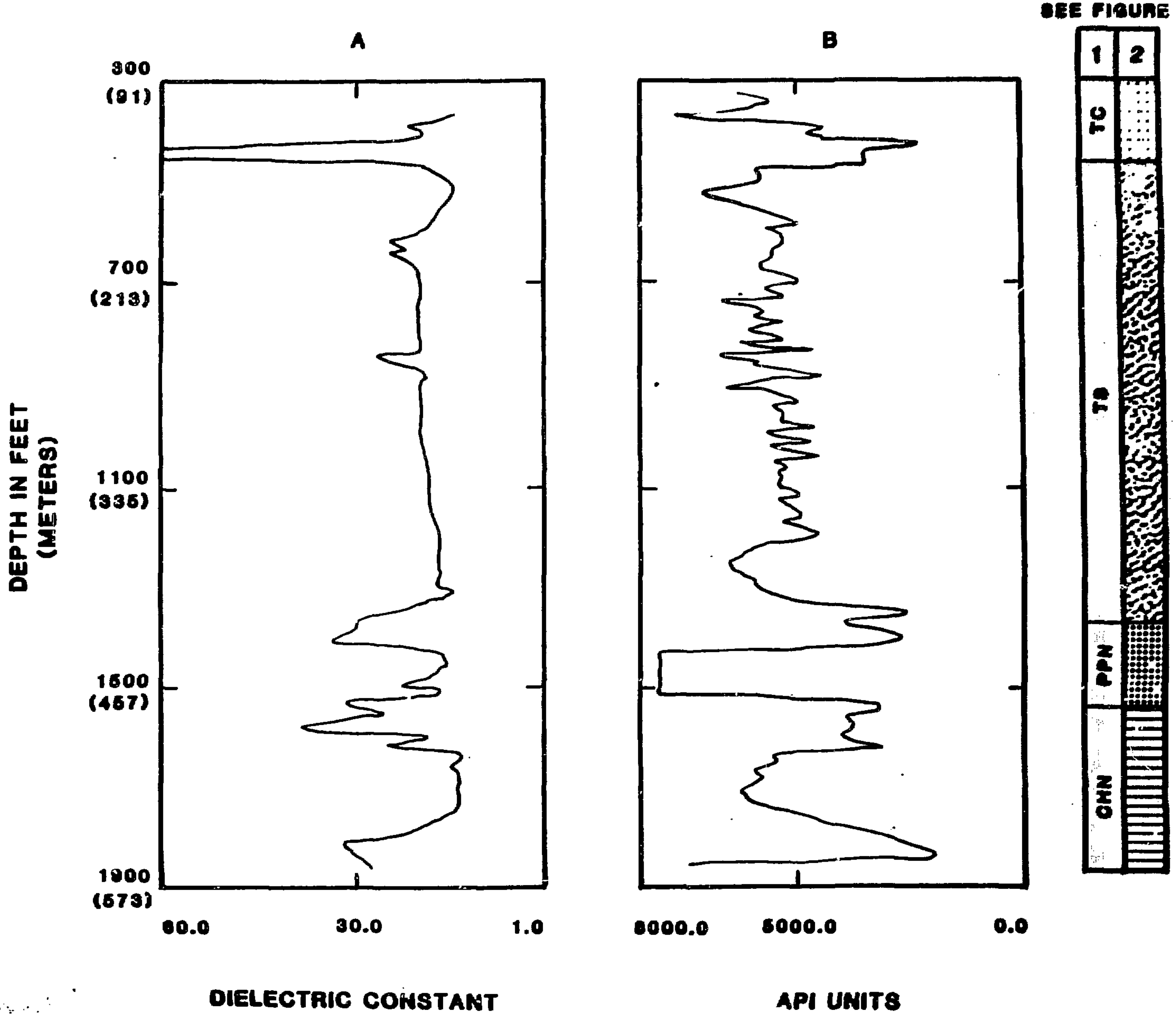


Figure [illegible].--Borehole USW UZ-6, water saturation derived from--(A) formation resistivity and (B) dielectric constant and porosity.

cementation factor of 0.3. Later, other values for the dielectric cementation factor were tested. It was determined that the best comparison between the moisture-content profile from drill cuttings and the calculated moisture-content values was obtained when the calculations were made using a dielectric cementation factor of 0.1 to 0.13 for various geologic members. This moisture profile was compared with the one obtained from drill cuttings; for borehole USW UZ-1 and for most of borehole USW UZ-6, correlation was good. The correlation of (A) dielectric-log-derived moisture profile, (B) drill-cuttings-derived moisture profile, and (C) the induction log, is shown in Figure 6 for borehole USW UZ-1, and in Figure 7 for borehole USW UZ-6. Moisture-content values were consistently greater on profiles derived from dielectric logs than on profiles derived from drill cuttings. For the interval from 1,350 feet to 1,400 feet (411 to 426 meters) in borehole USW UZ-6, the moisture curve derived from the dielectric log indicated substantial moisture content, but the profile derived from drill cuttings indicated little moisture content. The drilling log indicated that drilling was suspended at this interval for 2 days, which delayed the sampling of the drill cuttings by about 3 days. Later, the induction log was studied again to recheck the moisture profile derived from the dielectric log; the induction log indicated less resistivity corresponding to substantial moisture content. For the same interval, the epithermal-neutron log also correlated very well with the moisture profile derived from the dielectric log. This log indicated greater hydrogen concentration (fewer API neutron counts) for this interval, which was interpreted as having a substantial moisture content. The epithermal-neutron log also was used for comparing the other zones with substantial moisture content in both the boreholes with the profiles derived from drill cuttings and the dielectric logs; the correlation was excellent. The correlation of (A) dielectric log and (B) epithermal-neutron log for the moisture zones is shown in Figure 8 for borehole USW UZ-1, and in Figure 9 for borehole USW UZ-6.

Conclusions

This study determined that geophysical well logs obtained reliable information even under less than optimum borehole conditions. Drill cuttings also supplied very useful information; however, other sources of information were necessary for measuring characteristics such as moisture content, which is sensitive to exposure to air and to timing of the sampling. The thickness of the moisture zones vary within a few feet from one log to another. Results need to be evaluated qualitatively rather than quantitatively. For future operations in boreholes of such large size, logging companies could be asked to change the source-detector spacing of nuclear-logging tools or the transmitter-receiver spacing of electromagnetic tools to provide better quality logs.

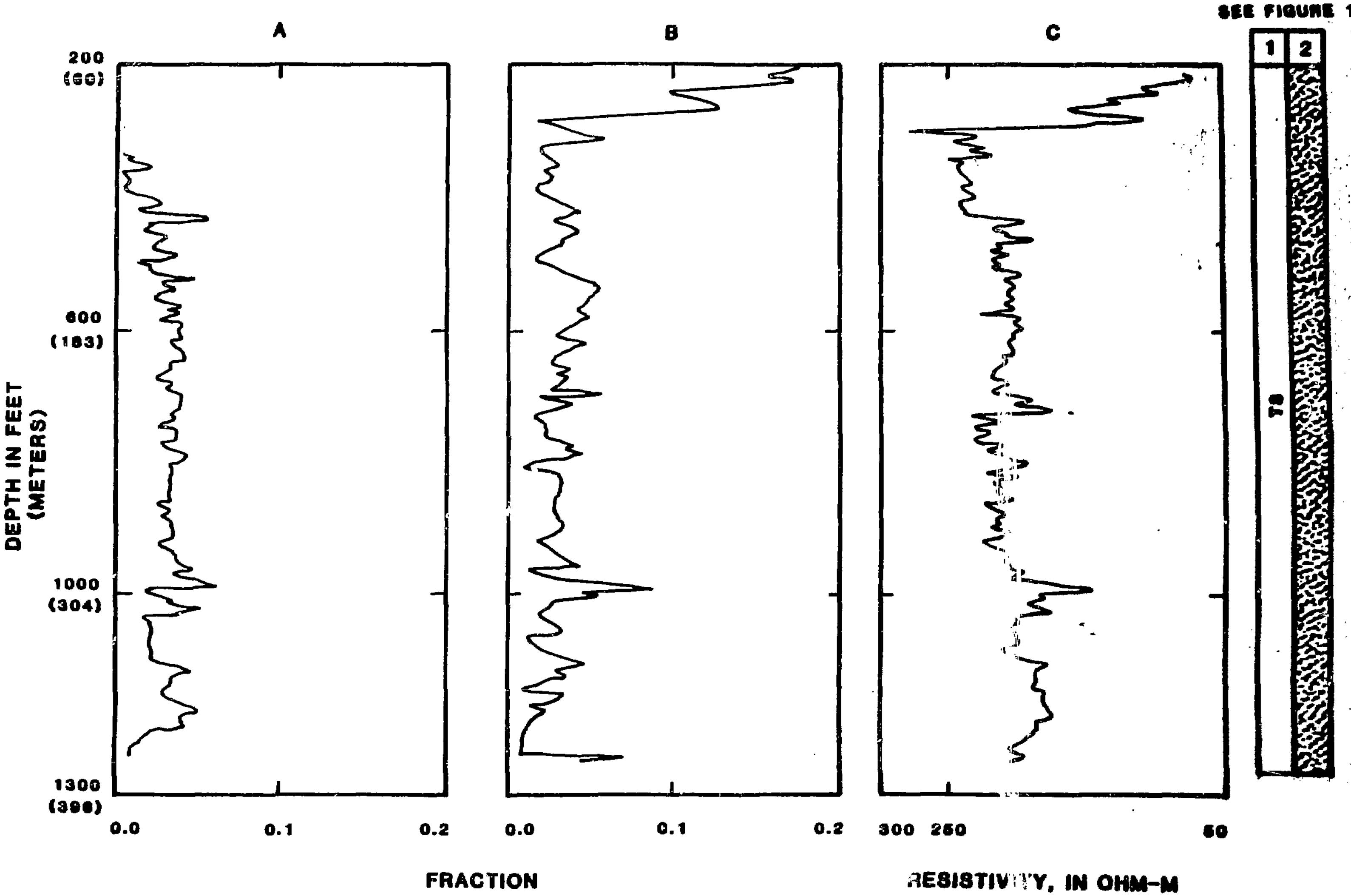


Figure 6. Borehole USW UZ-1, moisture-content profiles derived from--(A) dielectric log, (B) drill cuttings, and (C) induction log.

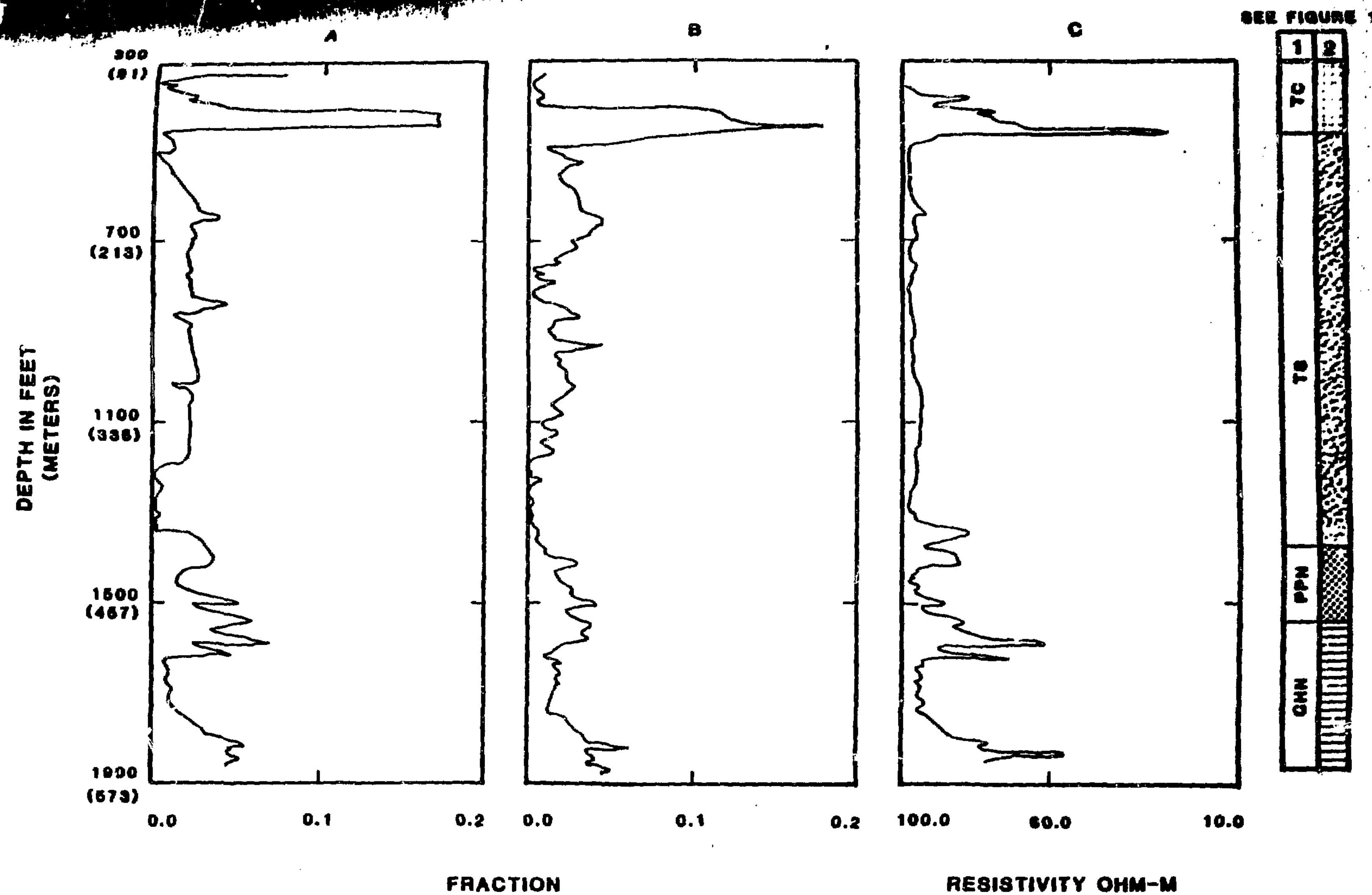
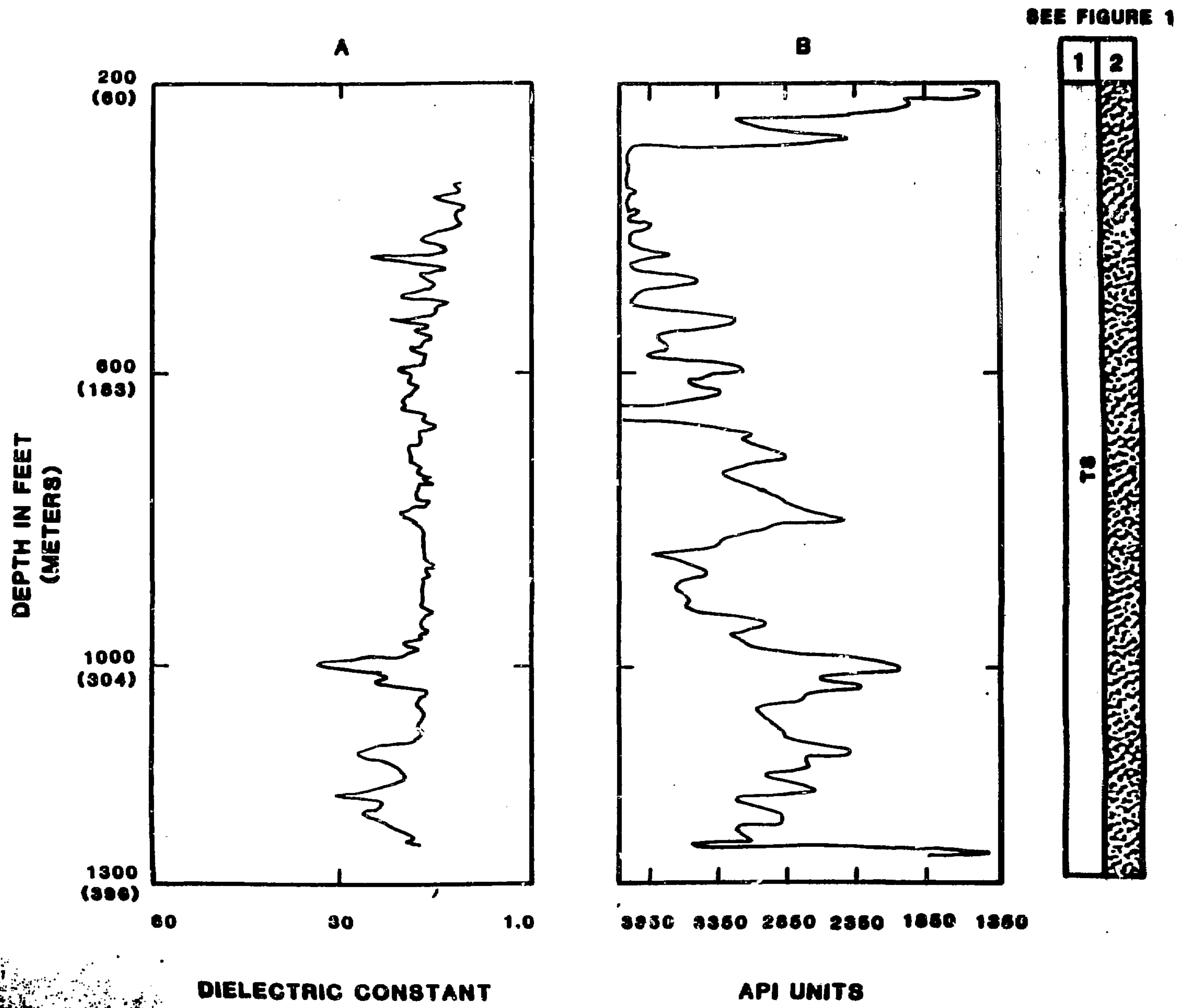


Figure 7. Borehole USW UZ-6, moisture-content profiles derived from--(A) dielectric log, (B) drill cuttings, and (C) induction log.



[illegible] correlation of--(A) dielectric log, and (B) epithermal-neutron log.

Figure 8. Borehole UNW [illegible] (A) dielectric log, and (B) epithermal-neutron log.

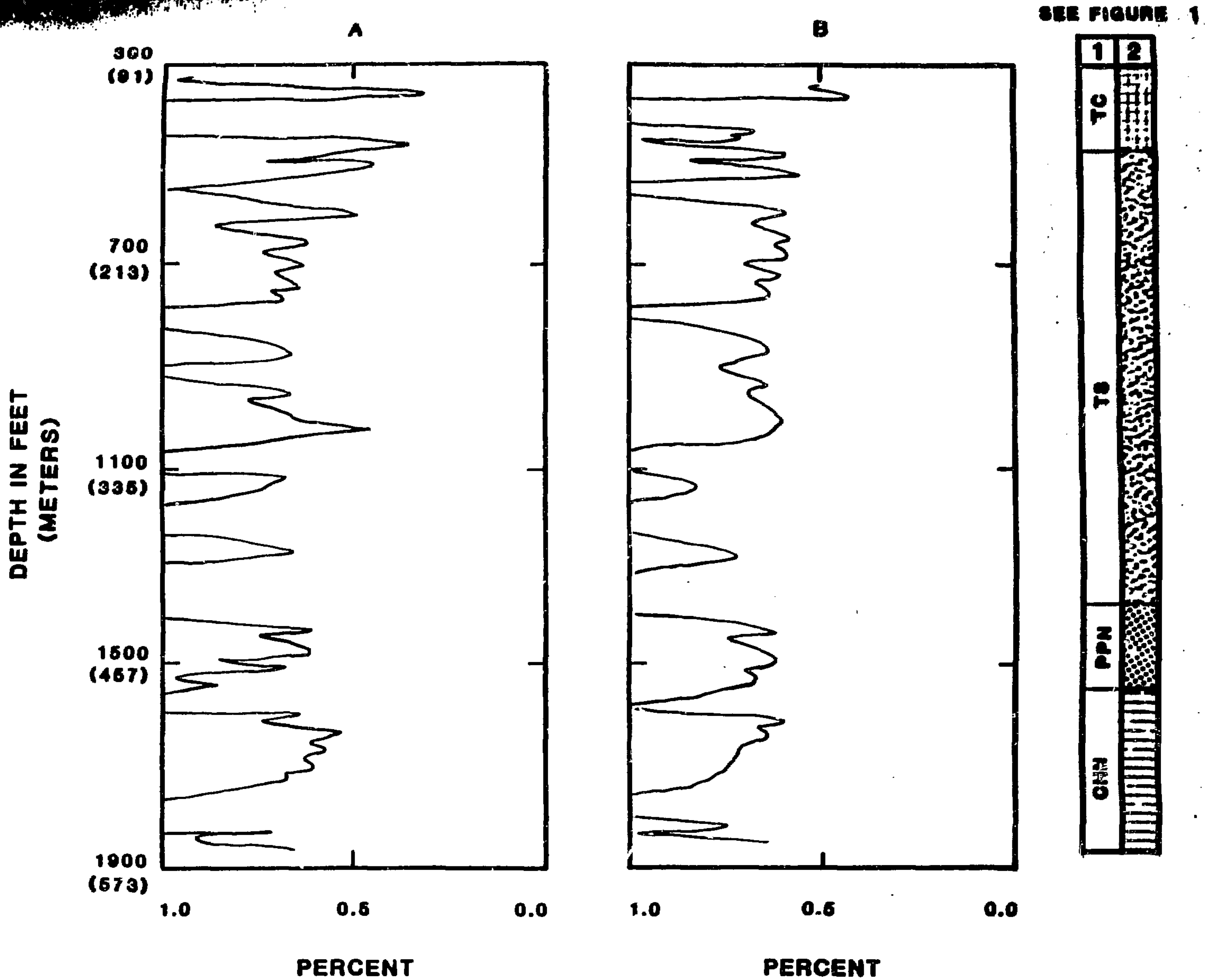


Figure 9. UZ-6, correlation of--(A) dielectric log, and (B) epithermal-neutron log.

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Biographical Sketch

Ibrahim Palaz received his bachelor of science degree in geophysics and geology from the University of Istanbul, Turkey, in 1978. He received his master of science degree in geophysics from Colorado School of Mines, Golden, in 1985. He is currently enrolled in the doctoral program at Colorado School of Mines and is a contract employee of the U.S. Geological Survey. His address is: U.S. Geological Survey, Box 25046, MS 416, Denver Federal Center, Denver, CO 80225.