In the late 1950's, the sonic log gained acceptance as a reliable porosity log; its measurement responds primarily to porosity and is essentially independent of saturation.

The sonic log, coupled with the focused resistivity logs — laterolog and induction — made possible modern formation evaluation from well logs. The sonic log provided a measurement of porosity; the focused resistivity logs, a measurement of true resistivity of the noninvaded virgin formation.

Subsequent improvements in sonic logging included the BHC borehole compensated sonic, the LSS* long-spaced sonic, and the Array-Sonic* tools. The latter tools permit the recording of the entire sonic wavetrain. From an analysis of the wavetrain, the shear and Stoneley transit times can be extracted as well as the compressional transit time.

The logging of formation bulk density, another measurement primarily dependent on formation porosity, was commercially introduced in the early 1960's. An FDC* compensated formation density log, which compensated for the mudcake, quickly followed in 1964. In 1981, the Litho-Density* log provided an improved bulk density measurement and a lithology-sensitive photoelectric absorption cross section measurement.

The recovery of physical rock samples and formation fluid samples with wireline tools also has a rich history. Sidewall coring, using a hollow, cylindrical "bullet" shot into the formation and retrieved by pulling it out, has existed since 1937. Obviously, this technique has undergone continuous improvement over the one-half century since its introduction. For very hard rocks, downhole mechanical coring tools exist that actually drill out the rock samples.

In 1957, a formation tester was introduced. It recovered a sample of the formation fluids and the pore pressure was measured during the sampling process. The FIT formation interval tester and the RFT* repeat formation tester have followed. The older tools could make only one pressure measurement and recover only one fluid sample per trip into the well; the RFT tool can make an unlimited number of pressure measurements and recover two fluid samples per trip.

To handle those formations in which the formation water is fresh, or varies in salinity, or in which the salinity is unknown, dielectric measurements have been developed. The EPT* electromagnetic propagation log was introduced in 1978; the DPT* deep propagation log, in 1985.

The preceding historical sketch has not, by any means, covered all the measurements now made with wireline well logging devices. Other logging measurements include nuclear magnetic resonance, nuclear spectrometry (both natural and induced), and numerous cased hole parameters.

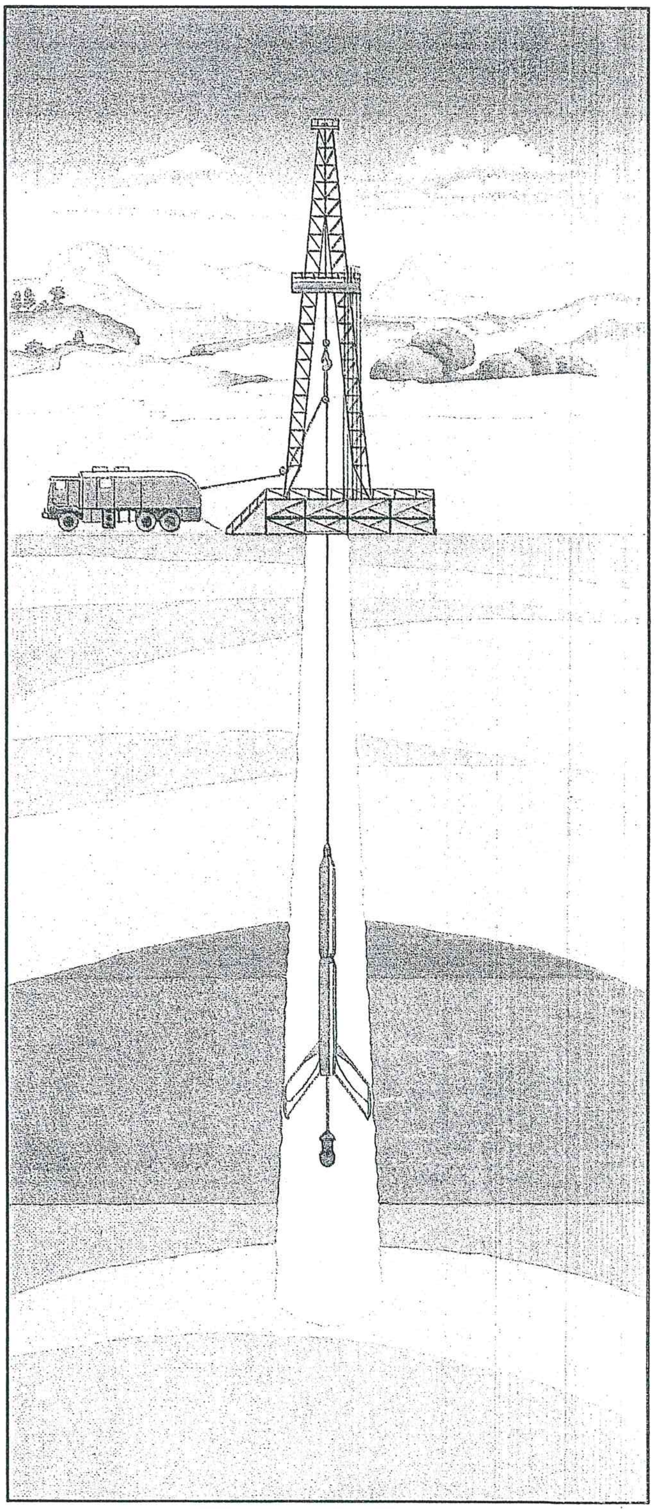


Fig. 1-2—Wireline logging operation.

THE FIELD OPERATION

Wireline electrical logging is done from a logging truck, sometimes referred to as a "mobile laboratory" (Fig. 1-3). The truck carries the downhole measurement instruments, the electrical cable and winch needed to lower the instruments into the borehole, the surface instrumentation needed to power the downhole instruments and to receive and process their signals, and the equipment needed to make a permanent recording of the "log."

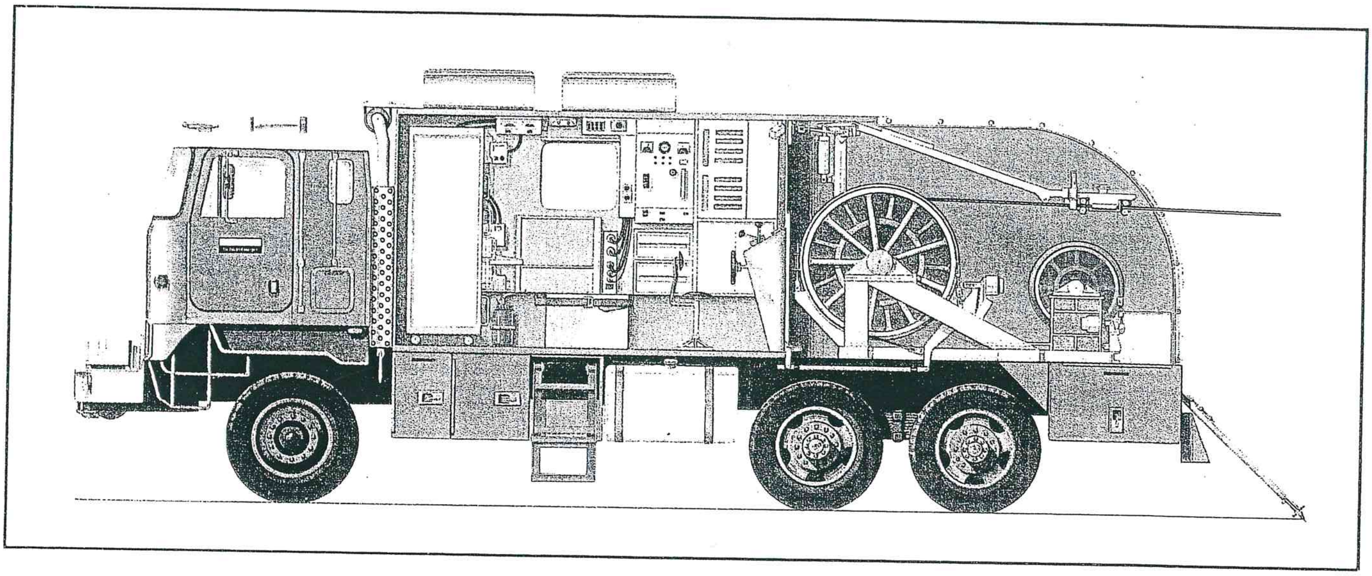


Fig. 1-3—A typical CSU wellsite mobile laboratory. The main winch contains up to 30,000 ft of seven-conductor logging cable; the optional small winch at the rear contains 24,000 ft of slim monoconductor cable for servicing producing wells under pressure. Data acquisition and computer equipment are inside the logging cab. For offshore-remote locations, the cab and winch assemblies are mounted on a skid.

The downhole measurement instruments are usually composed of two components. One component contains the sensors used in making the measurement, called the sonde. The type of sensor depends, of course, upon the nature of the measurement. Resistivity sensors use electrodes or coils; acoustic sensors use transducers; radioactivity sensors use detectors sensitive to radioactivity; etc. The sonde housing may be constructed of steel and/or fiberglass.

The other component of the downhole tool is the cartridge. The cartridge contains the electronics that power the sensors, process the resulting measurement signals, and transmit the signals up the cable to the truck. The cartridge may be a separate component screwed to the sonde to form the total tool, or it may be combined with the sensors into a single tool. That depends, of course, upon how much space the sensors and electronics require and the sensor requirements. The cartridge housing is usually made of steel.

Today, most logging tools are readily combinable. In other words, the sondes and cartridges of several tools can be connected to form one tool and thereby make many measurements and logs on a single descent into and ascent from the borehole.

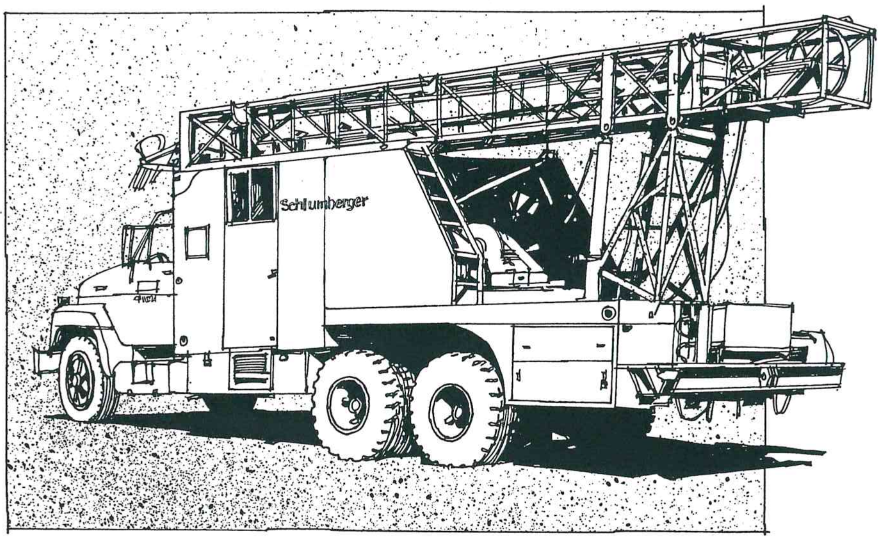
The downhole tool (or tools) is attached to an electrical cable that is used to lower the tool into and remove from the well. Most cable used in openhole logging today contains seven insulated copper conductors. New cable developments include a fiber optics conductor in the center of six copper conductors. The cable is wrapped with a steel armor to give it the strength to support the tool weight and provide some strength to pull on the tool in case it becomes stuck in the borehole. The cable and tools are run in and out of the borehole by means of a unit-mounted winch.

Well depths are measured with a calibrated measuring wheel system. Logs are normally recorded during the ascent from the well to assure a taunt cable and better depth control.

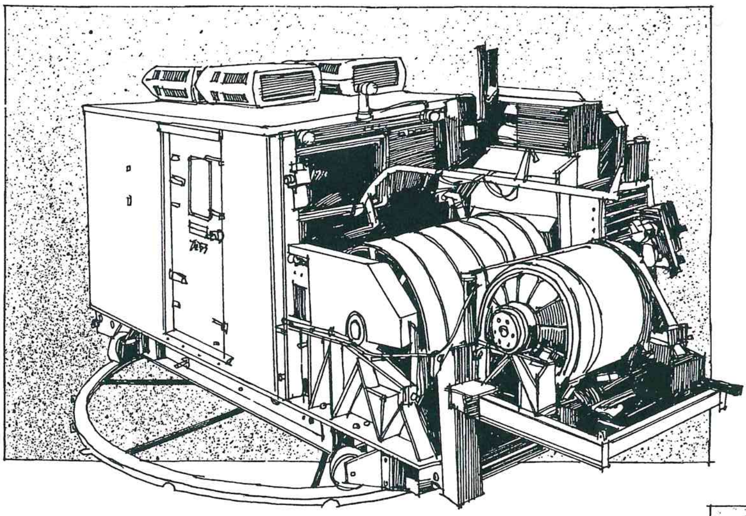
Signal transmission over the cable may be in analog or digital form; modern trends favor digital. The cable is also used, of course, to transmit the electrical power from the surface to the downhole tools.

The surface instrumentation (Fig. 1-4) provides the electrical power to the downhole tools. More importantly, the surface instrumentation receives the signals from the downhole tools, processes and/or analyzes those signals, and responds accordingly. The desired signals are output to magnetic tape in digital form and to a cathode-ray tube and photographic film in analytical form.

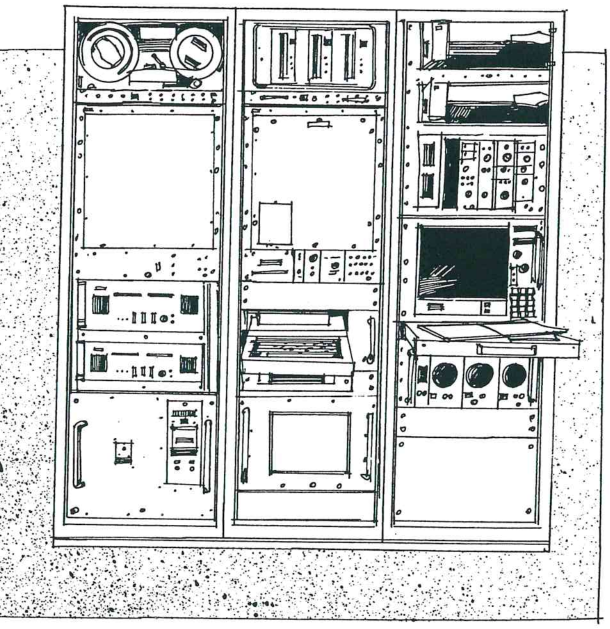
The photographic film is processed on the unit, and paper prints are made from the film. This continuous recording of the downhole measurement signals is referred to as the log.



This special-purpose unit is equipped with a mast.



The standard offshore unit is used for Production Service operations on drilling platforms. Smaller transportable units are available for other applications.



The standard Production Services field units have the computerized CSU* instrumentation system.

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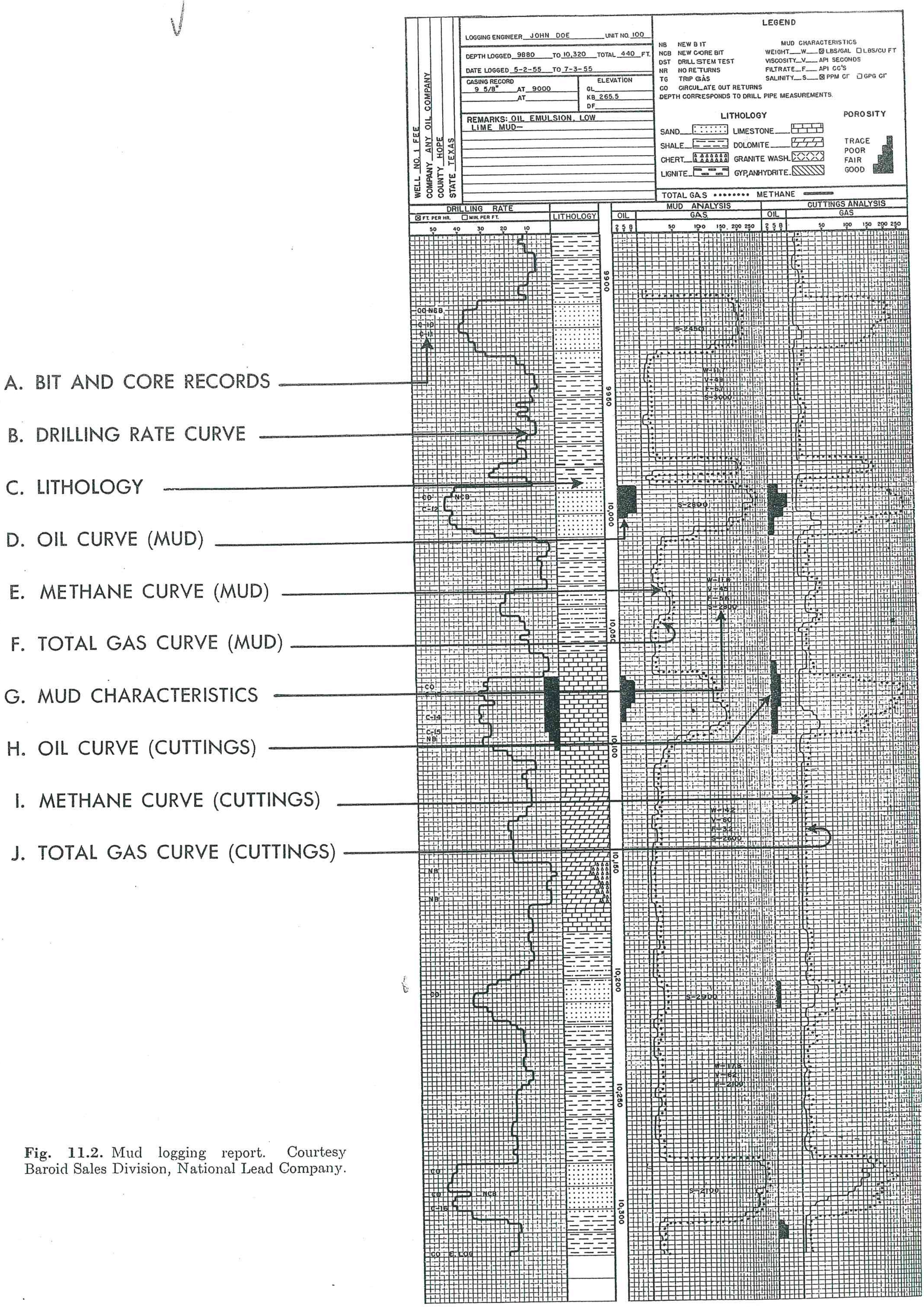
*Mark of Schlumberger



WELL NO. 1 FEE
COMPANY ANY OIL COMPANY
COUNTY HOPE
STATE TEXAS

LOGGING ENGINEER JOHN DOE UNIT NO. 100
DEPTH LOGGED 9880 TO 10,320 TOTAL 440 FT.
DATE LOGGED 5-2-55 TO 7-3-55
CASING RECORD 9 5/8" AT 9000
AT
ELEVATION
GL
KB 265.5
DF
REMARKS: OIL EMULSION, LOW LIME MUD—

LEGEND

NB NEW BIT
NCB NEW CORE BIT
DST DRILL STEM TEST
NR NO RETURNS
TG TRIP GAS
CO CIRCULATE OUT RETURNS
DEPTH CORRESPONDS TO DRILL PIPE MEASUREMENTS.

MUD CHARACTERISTICS
WEIGHT__W__ ☒ LBS/GAL ☐ LBS/CU FT
VISCOSITY__V__ API SECONDS
FILTRATE__F__ API CC'S
SALINITY__S__ ☒ PPM Cl⁻ ☐ GPG Cl⁻

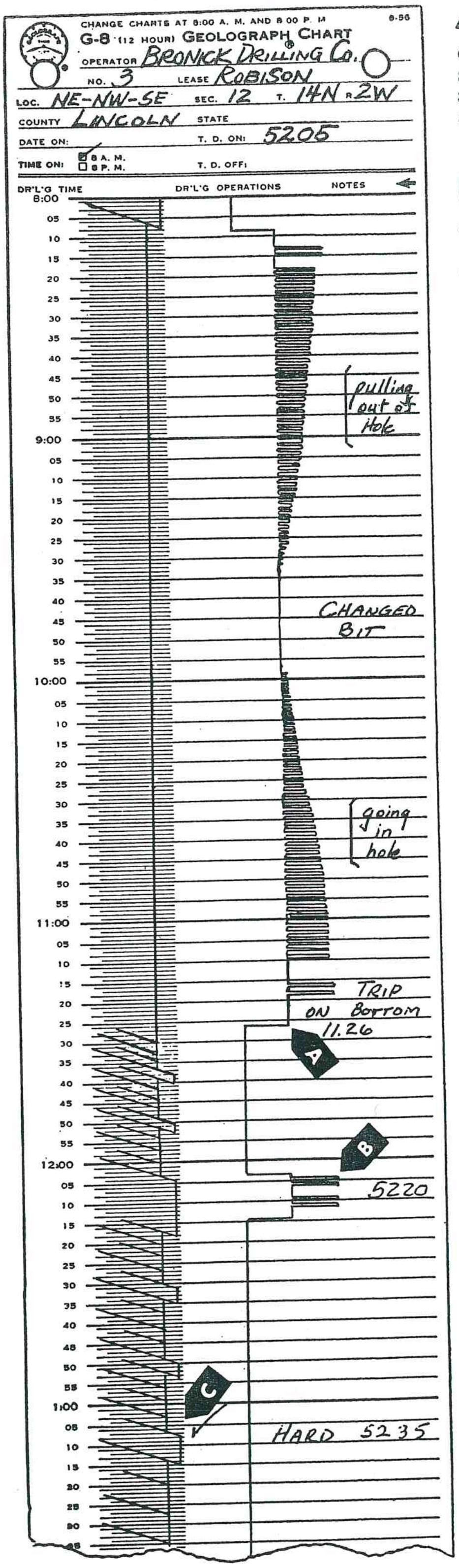
LITHOLOGY
SAND ⁚⁚⁚ LIMESTONE ▦
SHALE ☰ DOLOMITE ▨
CHERT △ GRANITE WASH ⊠
LIGNITE ▬ GYP, ANHYDRITE ▧

POROSITY
TRACE
POOR
FAIR
GOOD

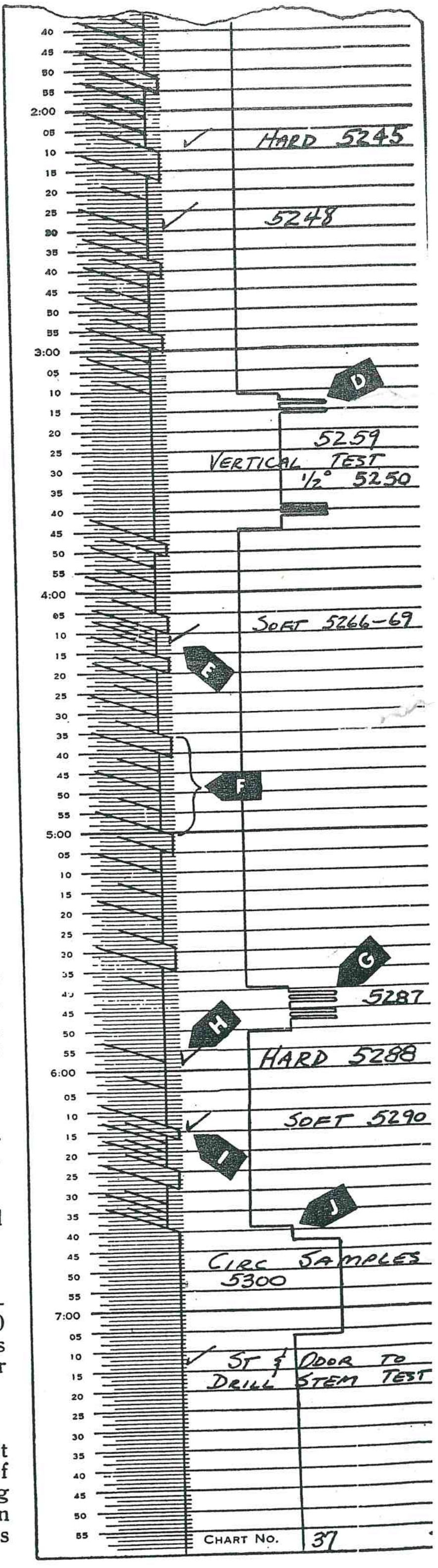
TOTAL GAS •••••••• METHANE ▬

Fig. 11.2. Mud logging report. Courtesy Baroid Sales Division, National Lead Company.

✓



CHANGE CHARTS AT 8:00 A. M. AND 8:00 P. M 8-56
G-8 (12 HOUR) GEOLOGRAPH® CHART
OPERATOR Bronick Drilling Co.
NO. 3 LEASE Robison
LOC. NE-NW-SE SEC. 12 T. 14N R. 2W
COUNTY Lincoln STATE
DATE ON: ✓ T. D. ON: 5205
TIME ON: ☑ 8 A. M. ☐ 8 P. M. T. D. OFF:
DR'L'G TIME DR'L'G OPERATIONS NOTES



A Line in drilling operations column moves to the left indicating that driller got on bottom with new bit and started drilling at 11:26. Total trip time, as indicated by "Trip Action", 3 hours and 17 minutes.

B This is the way a connection looks on the Geolograph chart. The driller raised the drill pipe from bottom at 12:03, broke out the kelly, picked up a single pipe (adding it to the drilling string), picked up the kelly and resumed drilling. This operation required 11 minutes, and the driller has written the depth of the hole, at that time, on the chart. Thus, every connection is a convenient datum for determining the depth of any drilling or down-time break, either immediately above or below.

C A 4-foot hard streak was encountered at 5,235 feet, as indicated by the increased spacing of the foot marks on this time chart.

D A connection was made at 5,259 feet and a vertical test was run at this point to determine the vertical deviation of the hole. The driller has noted on the chart that the test was actually taken at 5,250 feet and the deviation was ½ degree. The vertical test and connection required 34 minutes.

E Soft bed was drilled from 5,266 to 5,269 feet. Because of the thinness of this bed, no core or drill stem test was attempted.

F This section represents 5 feet of drilling. Note that every 5 feet the base line is offset for 1 foot, making a convenient marker for determining the depth of significant drilling changes.

G Connection was made at 5,287 feet. Note similarity to the record at "B".

H A hard streak was encountered from 5,288 to 5,290 feet.

I At 5,290 feet, the formation softened, drilling continued to 5,300 feet where the driller was given orders to cease drilling and circulate for samples.

J Circulating for samples started at 6:39 as indicated by movement of the line to the right. After circulating for 35 minutes, samples showed stain and odor, and a drill stem test was ordered.

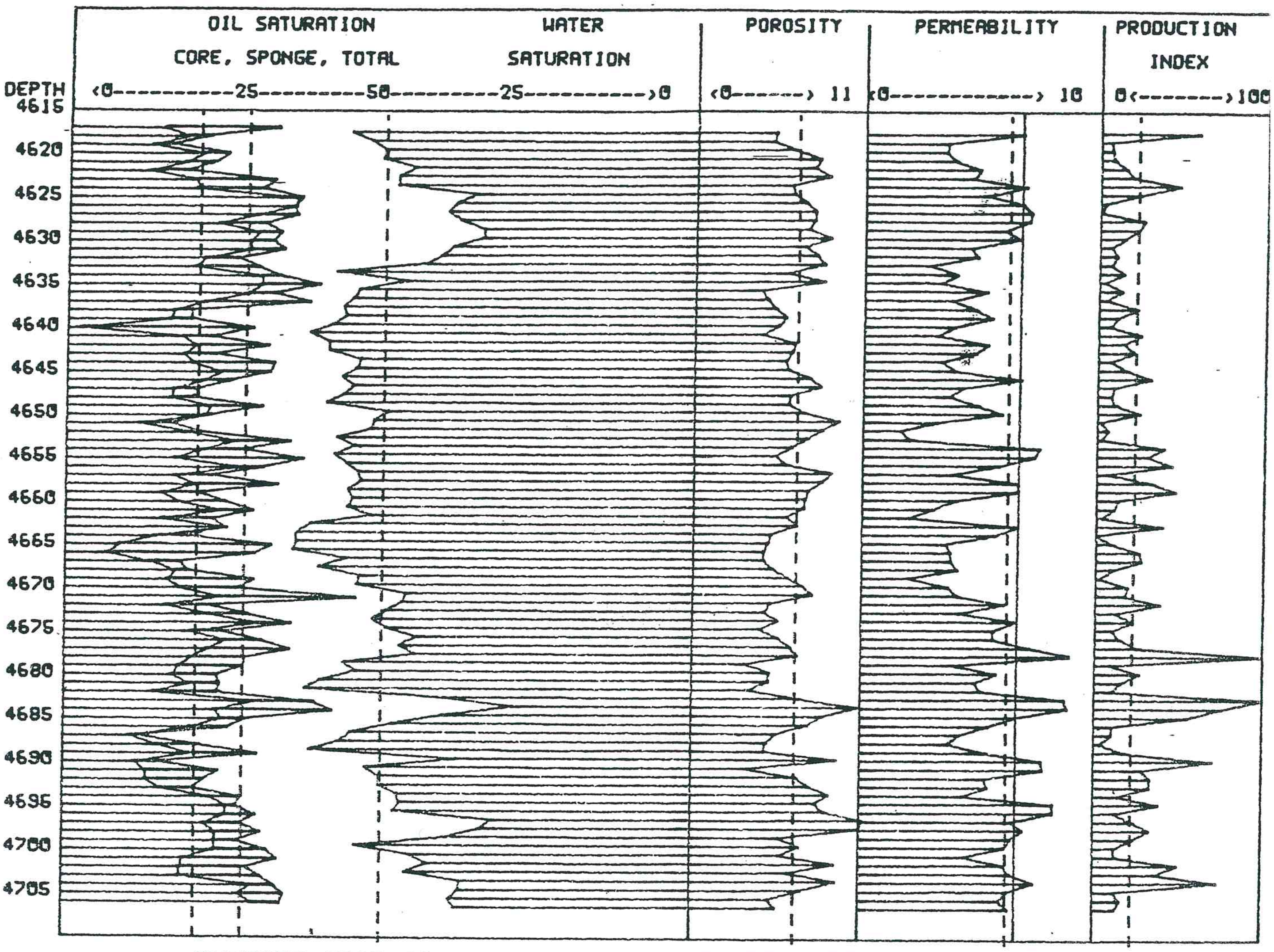
Fig. 11.1. Typical mechanical drilling log record. Courtesy Geolograph Mechanical Well Logging Service.

Drillers Logs

DOWDCO SPONGE CORE DATA GRAPHICS

MAJOR OIL COMPANY SPONGE WELL #1

SAN ANDRES FORMATION ECTOR COUNTY TEXAS



AVERAGE CORE OIL: 21.5 AVERAGE TOTAL OIL: 29.8

AVERAGE SPONGE OIL: 8.3 AVERAGE WATER SATUR.: 50.7

AVERAGE POROSITY: 6.7 AVERAGE PERMEABILITY: .7

FORMATION VOLUME FACTOR: 1.1

ments of rock properties, such as those obtained from downhole logs, pressure build-up analysis and seismic surveys. In general, however, these formation evaluation techniques yield *average* properties over several feet to several hundred feet of vertical section. All can determine properties at a greater distance from the wellbore than seen by a single core, but none yields as detailed information on vertical section properties and heterogeneity as may be obtained from core studies. In fact, gathering core data enhances the understanding of response in these other important formation study tools.

Thick formations of constant and known chemical composition that have undergone little alteration after deposition, that contain no mineral impurities within the pore space, or that have water of constant salinity, can likely be evaluated adequately without cores for completion purposes or to determine oil-in-place. Unfortunately, this ideal case is seldom encountered in the real world, and core data are still required to evaluate subsequent improved recovery schemes.

CONSIDERATIONS PRIOR TO CORING

When sampling a particular reservoir, coring operation objectives should be clearly defined and established early. These objectives influence the type of core to be cut, its size, coring fluid to be used and the analysis to follow. Most coring devices require that a coring point be predetermined so that the tool may be attached to the bottom of the drillstring. Unless a total section in the well is to be cored, some geologic control is required. Otherwise, data such as gas shows, oil shows or drilling breaks supplied by a hydrocarbon well logger are used to indicate the coring point.

One type of wireline coring tool allows a center plug to be recovered from the drill bit so that coring can be done at any selected depth. Another tool allows recovered cores to be spatially oriented, while others allow reservoir pressure to be maintained during core recovery. All of these, run at the bottom of the drillstring, supply a continuous vertical section of core from 2 to 8 in. in diameter from which needed information may be derived.

Percussion sidewall and the sidewall drilled cores now under development have a unique advantage in that coring points are selected after the well is drilled and downhole logs have been run to identify zones of interest. Unfortunately, these devices do not furnish a continuous core, since they sample small portions of the reservoir at selected intervals. While they are of tremendous value in formation evaluation and for petrographic studies, alteration of percussion sidewall cores makes them unsuitable for the *special core analysis* tests that furnish hard engineering data. It is anticipated, however, that tools such as the new sidewall device designed to drill 1-in.-diameter cores at right angles to the wellbore will overcome this latter limitation.

CORE ANALYSIS

Conventional core analysis. Of all commonly available coring methods, this is the most important source of information in that it furnishes measured values of basic rock properties. Porosity, permeability, residual fluids, lithology and texture are some of the parameters that characterize a core vertically, and representative samples are commonly taken every foot (and more frequently when core examination indicates the need).

A quick look at these cores and their tabulated and plotted data identifies zones of greatest storage capacity (porosity), greatest flow potential (permeability) and the presence of and magnitude of residual oil (Fig. 1). Relative changes in these properties with depth are easily observed, and average properties of selected zones can be compared for relative quality. Grain size, an indication of sorting, color of the rock, presence of laminations and other important structures are described. Fractures, vugs, and color, intensity and distribution of oil fluorescence are also reported. Supplementary data such as grain density, grain size distribution, cation exchange capacity and acid solubility typically are furnished on request.

TABLE 1—Geological data obtained by core analysis

- Formation lithology (sandstone, limestone, dolomite, etc.)
- Texture (grain size, distribution, and orientation)
- Sedimentary structures (laminations, cross-bedding, root casts, worm burrows)
- Porosity type (storage capacity)
    - intergranular
    - intragranular
    - intercrystalline
    - vugular-moldic
    - fracture
    - microporosity
- Permeability (flow capacity)
- Rock color
- Presence or absence of oil (fluorescence)
- Formation presence and thickness (tops and bottoms)
- Formation sequence
- Formation age, facies and correlation (biostratigraphy)
- Depositional environment
- Fracture definition
    - depth and occurrence
    - length
    - dip angle
    - dip azimuth
    - width
    - mineralization
    - staining
- Diagenesis (chemical, physical and biologic changes after deposition)
- Geochemical (source bed studies)
    - organic richness
    - type of organic matter
    - thermal maturity
    - liquid hydrocarbon potential
- Trace elements and insoluble residues
- Paleomagnetism
- Permanent record of core appearance and fluorescence (core photo)

TABLE 2—Completion data obtained by core analysis

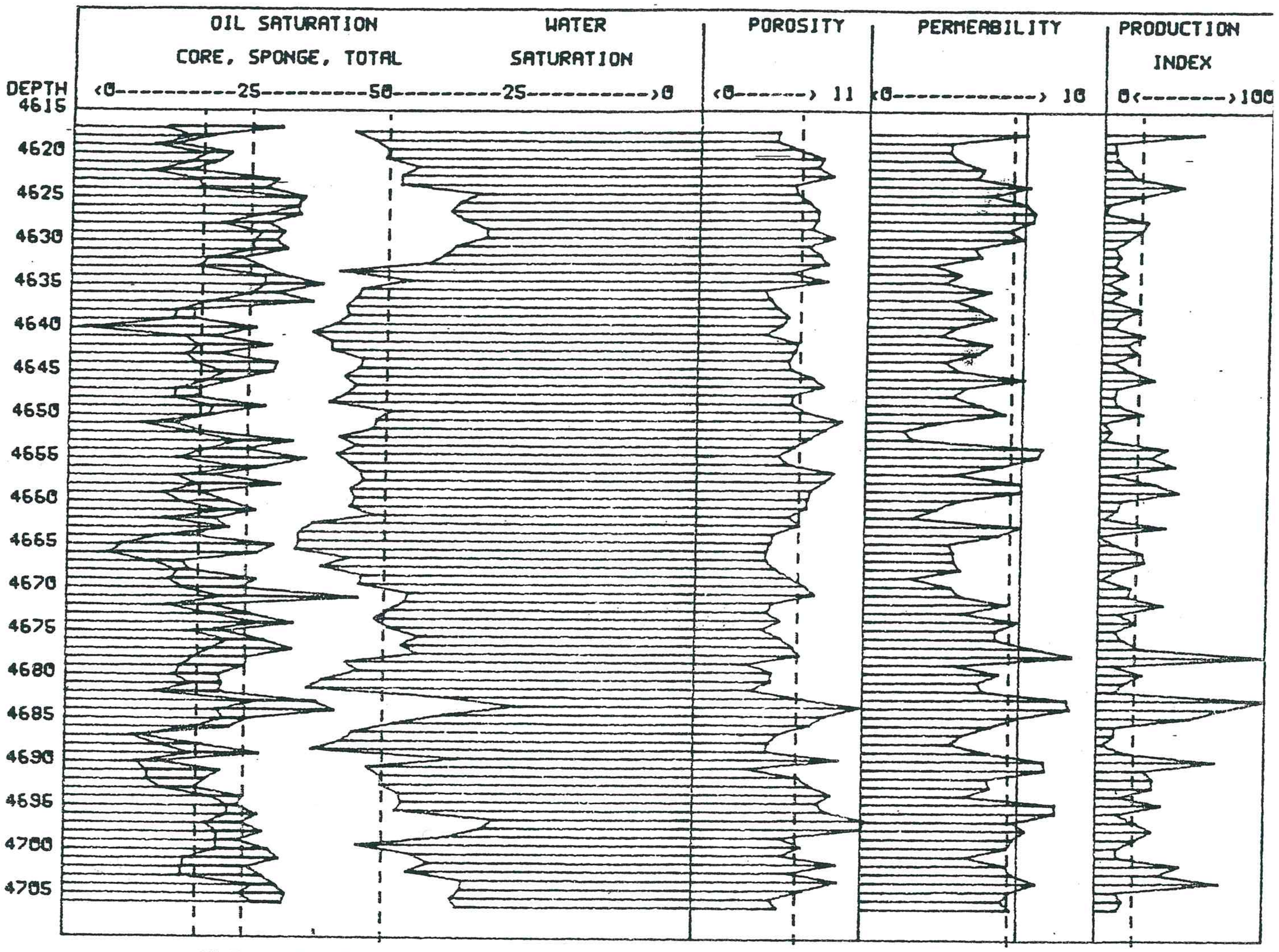
- Mineralogy (fabric and pore filling minerals type and occurrence)
- Clay morphology (form and structure)
- Clay distribution and quantity
- Porosity magnitude and distribution
- Residual oil quantity and distribution
    - Type of fluid production expected
    - Gas-oil and oil-water contacts
- Grain size distribution (gravel pack selection)
- Formation-rock compatibility with completion and workover fluids
- Vertical permeability (define need for frequency of perforations and cross flow expected)
- Horizontal permeability (selection of perforation intervals)
- Critical water estimates (quantity of water held immobile)
- Acidization susceptibility and fracture treatment design

Core photography offers a permanent and objective record of both the core's appearance and fluorescence (Fig. 2). The presence of oil-saturated rock and non-fluorescing shale zones are thus documented, and a record of the preserved core is established. This is of particular value for needs that may occur years after the core is cut (i.e., net pay determination) or when well participants are located at prohibitive travel distances from the point of analysis. Color videotape

DOWDCO SPONGE CORE DATA GRAPHICS

MAJOR OIL COMPANY SPONGE WELL #1

SAN ANDRES FORMATION ECTOR COUNTY TEXAS



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