WELL LOGGING

in Nontechnical Language

2nd Edition

Contents

A Word to the Reader

If you are interested in well logging, or if you work with well logs but don't know much about them, then this book is for you. *Well Logging in Nontechnical Language, 2nd Edition,* is an elementary yet practical text written for secondary users of logs—bankers, landmen, geology and engineering technicians, clerks, assistants, and secretaries—who come across logs in their daily routines and would like to make sense of those wiggly lines.

Before we begin, though, let's assess your needs. What is your interest in logging? Why do you want to know about logs? How much do you want to know? What are you going to do with the information? Most important, what can you expect to learn from this book? Will it make you an expert in log interpretation, or will it just make you dangerous?

Obviously, only you can answer the first couple of questions. If you have a passing or casual interest in logs, you've come to the right place. Maybe you've found yourself seated across a conference table from someone waving a log in one hand and a cigar in the other, swearing that his log is proof of the opportunity of a lifetime. On the other hand, maybe you've filed and handled logs day after day with only a vague idea about what they reveal. You may not want to become a petroleum geologist, engineer, or log analyst; however, you do want a solid background in logging so you can make more competent business decisions. Again, this book will help you.

What will you learn from this book? Well, after reading it, you'll be conversant with the main types of logs in use today—mud logs, open-hole and cased-hole wireline logs, computer-generated logs, and measurement-while-drilling logs. You'll be familiar enough with the more common types of open-hole logs to recognize productive zones and wet zones in simple cases. In addition, you'll know where to go for help with the more difficult cases. Though you won't be an expert, you'll know enough to ask the right questions. You'll also know when you have enough information to make a decision and, more importantly, when you don't.

This book is not the last word on the subject. It is a rudimentary, introductory explanation of a highly complex and technical subject. Use it as such. If you need to make an important decision based on the information contained in a set of logs, get help. Whenever you have money riding on the correct interpretation of a set of logs, seek expert advice from a consulting log analyst or from a log analyst/salesperson working for one of the major logging companies.

A second word of caution concerns the use of the logs. We can seldom measure directly the substance we are looking for (oil or gas). Instead, we make inferences and best guesses based on sophisticated measurements of other parameters. From these inferences, we formulate our interpretations. But think about it for a minute. If logs always succeeded in their predictions, if people interpreted them perfectly, and if logging tools never malfunctioned, logging companies wouldn't need the escape clause that is attached to all of their interpretations.

What is the escape clause? In essence, it states that we live in an imperfect world, full of well-intentioned but sometimes inept people; that machines and electrical instruments sometimes fail; and that occasionally interpretations will be wrong. Companies tell you this to underscore the high risk in any drilling venture. Logging companies and log analysts (and authors) are entirely blameless for any losses incurred as a result of these failures. We agree with these sentiments.

A book such as this one, which tries to translate a very technical subject into layman's terms, can never be as precise or exact as a technical treatment of the same subject matter. This book is a compromise between rigorous exactness and oversimplification. We hope we have hit a middle ground where the explanations are correct but simplified. We have often omitted or greatly abbreviated tool design principles and acquisition procedures and have presented only a couple of the many methods of interpretation available today. As we stated previously, we are not trying to make log analysts out of our readers; rather, we want to give them an appreciation for the process.

This book is aimed primarily at the petroleum industry. Oil and gas well logging accounts for most of the logs that are run. Nonetheless, there are several other branches to the logging family tree. A growing segment consists of using logging to evaluate mineral deposits for mineral exploration. Logs also play a role in geotechnical engineering, such as the study of the famous San Andreas fault; in environmental impact evaluation and monitoring of waste disposal wells; and in scientific investigation (many logs have been run for the federal government in monitoring and evaluating shot holes for underground atomic weapons testing). The logs used in this type of work are generally the same as those used in petroleum logging; so although your particular application may not be mentioned, this book describes the logs that you might use.

The examples in this book are mainly from the United States—not because they are unique, but because they were handy. An example is just that—an example, illustrating a point. It is not necessary to cover every geologic province in order to apply the methods described here to your particular part of the world. The units of measurement used in the book are those that were used for the log examples: English units. Many logs are run in metric units, but this should be of little importance to the reader because units of measurement are always noted on the log heading and scales.

Regardless of your interest in logs, the part of the world where you want to use them, or the measurement system that you prefer, this book should get you started in understanding petroleum well logs.

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Introduction to Logging

Just what are well logs and how did they get their name? One story goes something like this. When the oil industry was getting started around the close of the 1800s, many sailors were out of work. (Curiously, the sailors were unemployed because the fledgling oil industry and kerosene were eliminating the need for whale oil.) Since the sailors were used to working at heights and with rigging, they were naturals at scaling the tall oilfield derricks.

Along with the influx of sailors came many of their nautical expressions. That's why the drilling derrick and its equipment are called a *rig*, the derrick is a *mast*, the changing room is called a *doghouse*, and the records are kept in the *knowledge box*. The term *log* is another of these merchant marine expressions.

Nearly everyone has heard of the ship's log kept by the captain. It's a chronological record of what happens aboard a ship. The record of what occurs on a drilling rig is the driller's log. Since oil companies are interested in what happens as a bit drills deeper into the earth, the driller's log is usually recorded by depth rather than by time.

In the early days of the industry, the driller's log was practically the only information available about the subsurface formations. On the driller's log were recorded the types of rock brought up from the borehole, how many feet per hour the bit was drilling, oil or gas flows, equipment breakdowns, accidents such as stuck drillpipe, and any other occurrence that might have a bearing on evaluating the well. Today, *log* has stretched to mean any data

Usually well-rounded sands are also well sorted, so they have very high porosities and permeabilities. (Permeability is the ability of a formation to allow fluid to flow. High permeability results in high production, low permeability in low production—other things being equal.) These sands are described as mature, well weathered, or even beach sand (if the grains are large). On the other hand, poorly sorted, angular, and subangular sands are said to be immature and slightly weathered with low porosities and low permeabilities.

Other Types of Porosity

Figure 3–2d also illustrates *fracture porosity.* If the bricks are rather loosely stacked, there will be spaces between them. These spaces are more in the nature of fracture planes than pore spaces. The total pore volume of a fracture system is usually very low—often 1–2%. Fractures occur naturally in rocks because of the way the earth moves and buckles over time. Although fractures have a very low porosity, they frequently have a very high permeability; large quantities of fluid can flow very easily.

Another type of porosity is *vugular porosity*, present in carbonates such as limestones and dolomites. A *vug* is a large, irregular void in the rock, usually caused when a mineral, such as calcite, is dissolved by water moving through the rock. Vugs allow large quantities of fluid to flow very easily. Caverns are examples of huge vugs.

A particular formation could have all three porosity systems or only one. Sandstones normally have only the first type of porosity, called *matrix* or *intergranular porosity.* Carbonates often have all three porosity systems: matrix, fracture, and vugular.

FORMATION ANALYSIS

Figure 3–3 illustrates some important concepts in formation analysis. Figure 3–3a depicts a unit volume of formation. This unit volume measures one unit (I) per side and has a volume of 1 cubic unit (a unit can be 1 foot, 1 inch, 1 meter—it really doesn't matter). We let the unit volume equal 100%. This means that if the unit volume is full of water, then we have 100% water. On the other hand, if the unit volume is completely filled by the matrix, then the porosity is zero and there is no water, oil, or gas present. Seldom is the porosity zero. As we saw in the previous section, if sand grains form the matrix or structure of the rock, the porosity will be well above zero in most cases.

Generally, the formation water surrounds the sand grains because of the preferential wetting of the formation by water. The water that wets the sand

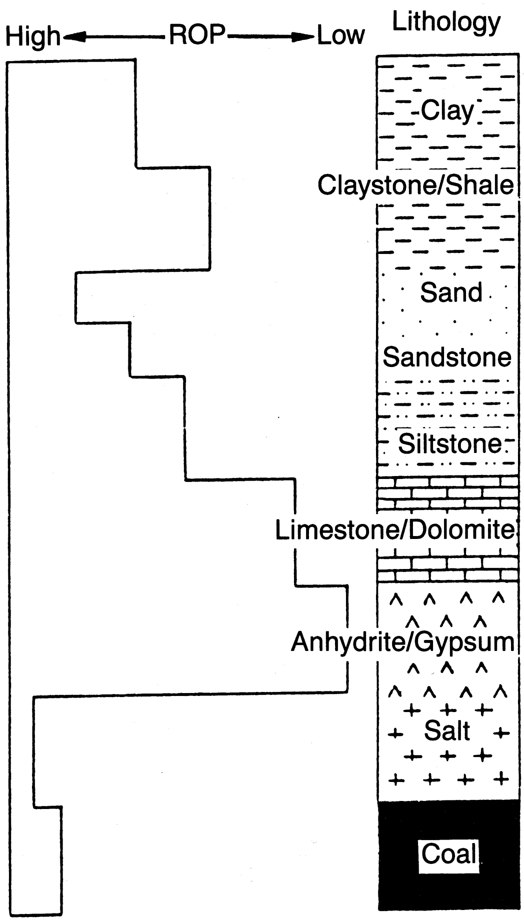

Fig. 4–3. *Drilling responses of common rock types (adapted from Anadrill's* Delta Manual, *9–3).*

GAS DETECTION

Gases extracted from the mud system are usually the first indication that hydrocarbons are present downhole. Gas enters the drilling fluid from one of three sources: (1) a gas-bearing formation, (2) a formation feeding gas into the mud, or (3) contamination.

are very difficult to read because of borehole effects and the many effects of the various electrode arrangements.

Figure 5–7 illustrates a simple four-electrode system called a *normal device*. There are usually two normal measurements on an electric log. One has a short spacing of around 10–16 in. The other, called the long normal, has a spacing of 64 in.

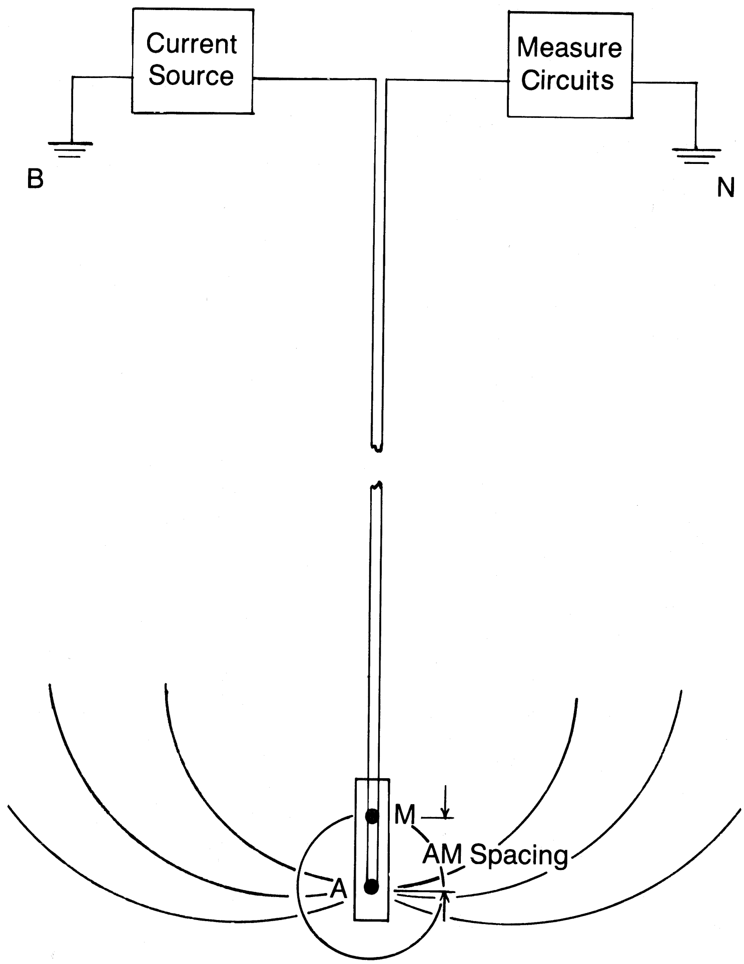

Fig. 5–7. *Schematic of electric log, normal device. Current flows from electrode A to ground electrode B. Voltage is measured by electrode M with respect to another ground electrode at N.*

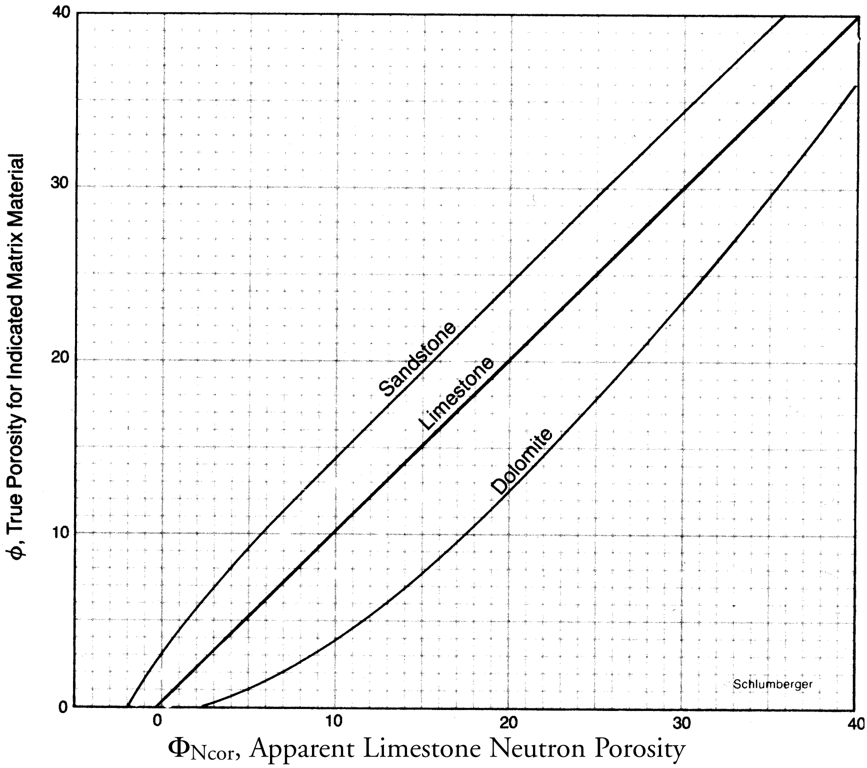

Fig. 6–8. *Neutron porosity equivalence curves (courtesy Schlumberger). Usually the neutron log is recorded in limestone porosity units (pu's). Use the chart to convert to other rock types.*

SONIC LOG

The *sonic* or *acoustic tool* uses sound waves to measure porosity. Let's take a quick look at sound waves and how they travel.

Sound is energy that travels in the form of a wave and has a frequency between 20 and 20,000 cycles per second (cps, or hertz). A sound wave (also called an acoustic wave) can travel in several different forms. The most common form is a compressional wave, the kind of wave that vibrates our eardrums so we can hear. Compressional waves are also called *P*-waves (primary waves) because they are the first waves to arrive.

A *P*-wave travels by compressing the material in which it travels. The material "moves" along the axis of the wave. An example of a *P*-wave is a Slinky™ spring toy that you hold outstretched vertically. If you lift a couple