Logging history rich with innovation

From bathtub experiments to modern nuclear physics, formation logging has been the backbone of oil and gas development, letting geologists, geophysicists and engineers see more and more of the subsurface.

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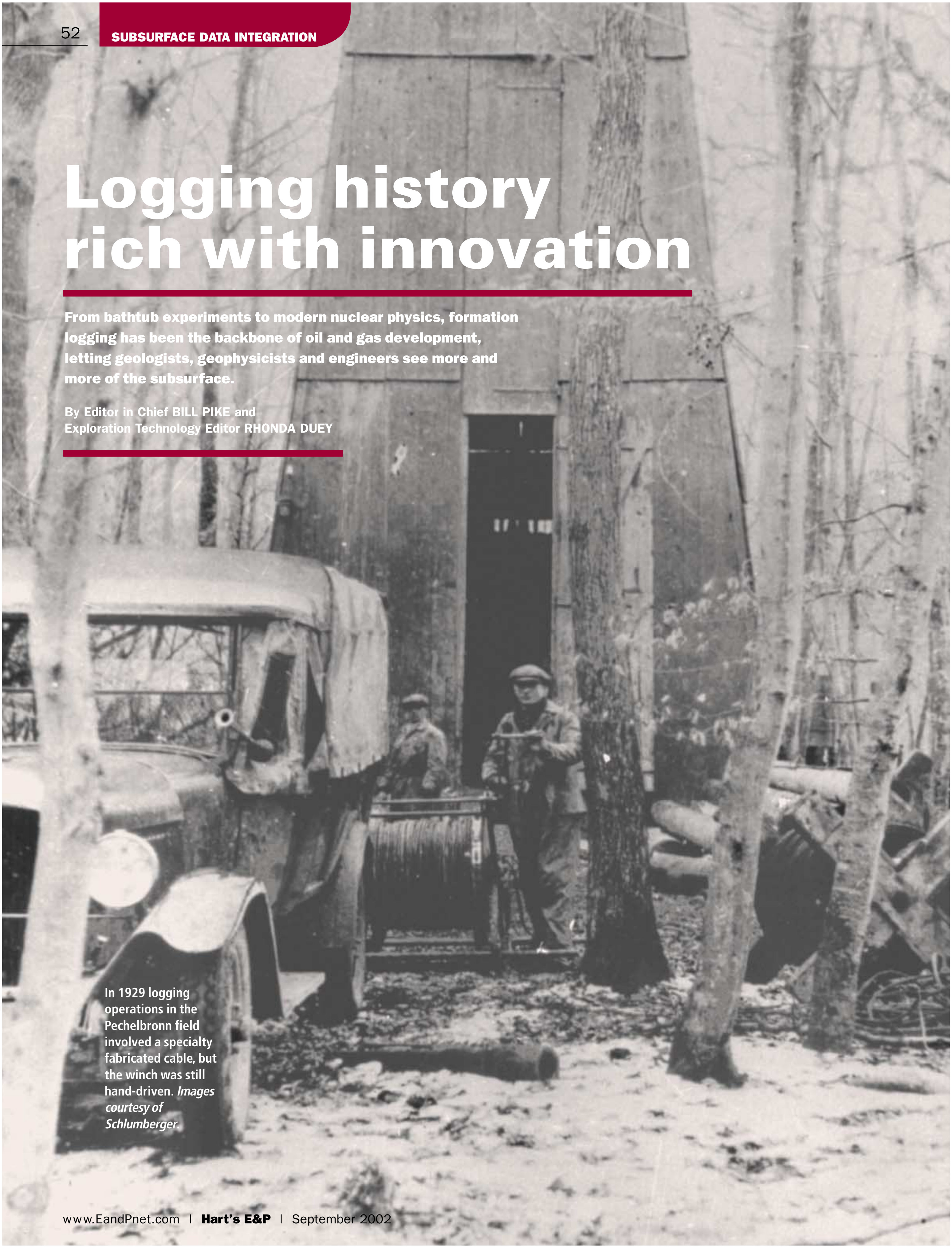

In 1929 logging operations in the Pechelbronn field involved a specialty fabricated cable, but the winch was still hand-driven. *Images courtesy of Schlumberger.*

The advent of well logging in the 1920s and its subsequent development into a sophisticated technology revolutionized the oil and gas exploration and production industry. The ability to "look and measure" such things as formation type, formation dip, porosity, fluid type and other important factors transformed the drilling and completion of oil and gas wells from an ill-defined art into a refined science. Logging development encompasses three major areas: electric logging, sonic or acoustic logging, and nuclear logging. An understanding of their development is an understanding of the industry's technical progress.

Electric logging

The genesis of electric well logging resides with Conrad Schlumberger, who while a physics professor at the Ecole de Mines de Paris, France, conceived the idea of prospecting for metal ore deposits by using their electrical conductivity to distinguish them from their less conductive surroundings. One of the first tests, according to Schlumberger historians, was performed in his bathtub, which was filled with various rocks for the experiment. Working with his brother Marcel Schlumberger, Conrad began a series of test surface surveys in Europe, Africa and North America over a 3-year period. Their discoveries included an oil-productive salt dome in Romania, a precursor of things to come.

In 1926, the brothers formed Societe de Prospection Electrique and began to develop the theory that adding resistivity information from deeper formations would increase the effectiveness of their surface prospecting. By lowering an electric sonde down a 1,600-ft (488-m) well in France's **Pechelbronn** field Sept. 5, 1927, the brothers created the first well log. This log was painstakingly recorded point by point, meter by meter, using makeshift equipment and then plotted by stitching together the successive readings (Figure 1).

The technology worked simply. Three electrodes – A, M and N – are lowered to the bottom of the wellbore on three insulated wires. Current from electrode A passes through the drilling mud and spreads out into the formation. The potentials measured at M and N are transmitted to the surface where they are measured. By measuring the potential difference between M and N, and the strength of current from A, the apparent formation resistivity is calculated (Figure 2).

Following the initial success with the first electric resistivity logs, logging technology began to develop rapidly. In 1931, the accidental discovery of spontaneous potential (SP), produced naturally by the borehole mud at the boundaries of the permeable beds, led to an innovative new logging technique – simultaneously recording SP and resistivity curves. This technique enabled producers to differentiate permeable oil-bearing beds from impermeable, nonproducing ones.

By 1936, the industry could augment resistivity logs with formation sample takers, automatic film recorders and multispacing resistivity curves for deep wells.

The 1940s were a period of rapid development in logging technology despite the intervention of World War II. In 1941, logging took another major step forward with the introduction of the spontaneous-potential dipmeter, which greatly improved the vertical resolution of openhole logs. The tool allowed the calculation of a layer's dip – the deviation of that layer from true horizontal – and the direction of the dip. This measurement was improved further with the resistivity dipmeter in 1947 and the continuous resistivity dipmeter in 1952.

During the 1940s, development in other areas forced innovations in logging. One of the most important was the introduction of oil-based mud (OBM) in the Rangely, Colo., oil fields in 1948. OBMs are nonconductive. Normally configured electrical surveys require a conductive mud (water-based) system.[1] The solution to logging in OBMs was the induction log, developed in the late 1940s. In induction logging, "high-frequency AC of constant intensity is sent through a transmitter coil. The alternating magnetic field thus created induces secondary currents in the formation (that) flow in circular ground-loop paths coaxial with the transmitter coil. These ground-loop currents, in turn, create magnetic fields that induce signals in the receiver coil. The induced receiver signals are essentially proportional to the conductivity of the formation."[2]

Throughout the 1950s and 1960s, electric logging continued to develop, but it was the computerized processing of logs that catapulted the sector ahead in 1962. Computerization allowed much faster log processing, thereby allowing the dramatic expansion of log data-gathering capability.

By 1970, the sector was poised on the brink of significant advances in logging technology, particularly in the field of nuclear logging. But advances still were being made in electric logging, especially in the area of mass and speed of data collection. The year 1971 saw the

Conrad Schlumberger prospects for metal ore deposits in Normandy, France, in the early 1920s using technology later employed in well logging.

introduction of combination logging systems. Combos allowed loggers to acquire different sets of data simultaneously rather than in sequential runs. Thus were born tools that provided gamma ray, SP, resistivity, sonic and caliper measurements in a single run.

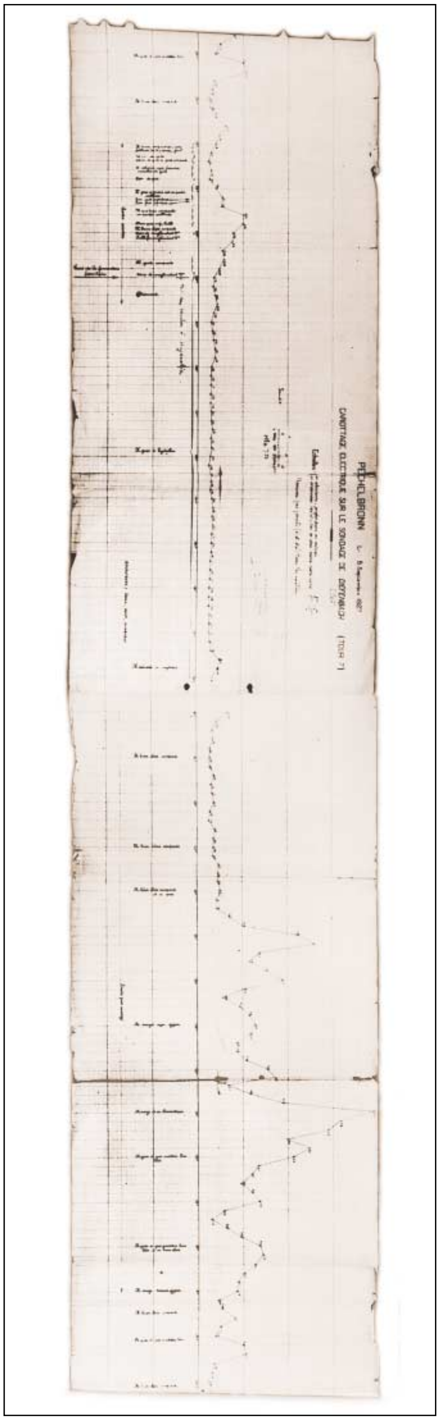

Figure 1. The first electric log was obtained Sept. 27, 1927, on the Diefenbach 2905 well, Rig. No. 7, at Pechelbronn, Alsace, France. The resistivity curve was created by plotting successive readings.

Sonic logging

In 1946, working in large part off technology developed during World War II, the logging sector produced the first sonic log, the casing collar locator. This technology allowed more accurate depth measurement inside casing and more exact placement of perforations and completion equipment. Sonic logs generally work by generating signals in the 20-kHz to 30-kHz range, although some tools operate at higher ranges. Most acoustic logging tools have centralizers at one end and three caliper arms at the other end to keep the tools centered in the hole. An acoustic wave transducer atop the tool generates the acoustic signal. Two receivers at the lower end of the tool receive the signal. "After a signal from a transducer travels through the fluid and strikes the borehole wall at the critical angle, a compressional wave is transmitted down the borewall in the direction of the receivers. As it propagates along the borewall toward the receivers, fluid waves are continually refracted back into the fluid. However, only two refracted ray paths are of interest: the ray paths taken back toward the two receiving transducers ... If we measure the difference in time of arrival of the compressional wave at the two receivers, we can determine the compressional wave travel time through the rock formation opposite the two receivers."[3]

During the next three decades, sonic logging moved into several measurement fields, including:

- porosity measurement;
- cement bond evaluation;
- fracture detection;
- lithology determination;
- mechanical rock properties measurement;
- borewall and casing inspection;
- seismic calibration;
- abnormal formation pressure detection; and
- gas-bearing formations identification.[4]

Although nuclear logging has supplanted some of its functions, acoustic logging remains a vital part of the logging suite and regularly is run in some form in combination logging tools.

Nuclear logging

Logging using radiation of nuclear origin got its start in 1940. The initial nuclear logging tools recorded "the natural gamma radiation emitted by the formations crossed through by boreholes. Of the three identified nuclear radiations – alpha, beta and gamma – only gamma radiation, which is of the electromechanical type, can be used in well logging because it alone has sufficient penetrating power to go through the formation and the steel casing."[5]

From passive radioactive monitoring in the gamma ray tool, the logging industry moved rapidly to active nuclear bombardment and measurement. In a formation density log, first introduced in 1962, the borehole wall is irradiated with a gamma ray source. A gamma ray counter then records the reflected rays. The number of gamma rays returned vs. those diffused relates to the density of the formation.

The industry took nuclear logging one step further with the introduction of neutron logs in the late 1960s. Neutron logs also measure returned gamma rays, but in this instance, those generated by fast- or slow-moving neutrons. Neutrons are emitted by mixed radioactive sources. "Most of the (neutron's) energy lost is done so during collisions with hydrogen nuclei … After having traveled a certain distance, a neutron becomes 'thermal' or 'slow' and is captured by an atom, which emits a capture gamma ray."[6] Since the distance a neutron can travel without hitting a hydrogen nuclei varies with the amount of hydrogen present, both porosity and formation contents can be determined. The original neutron logs were augmented later by pulsed neutron logs and neutron spectroscopy logs.

One of the biggest breakthroughs in recent logging history has been the advent of nuclear magnetic resonance (NMR) logging. The technology has proven more potentially beneficial and more confounding than its early developers could have imagined.

NMR tools function by creating a magnetic field in the borehole and then sending out pulses that polarize the hydrogen in water, oil and gas in the formation. As these hydrogen nuclei realign themselves to the original magnetic field, they induce signals in the tool's receiver, which are recorded by electronics.

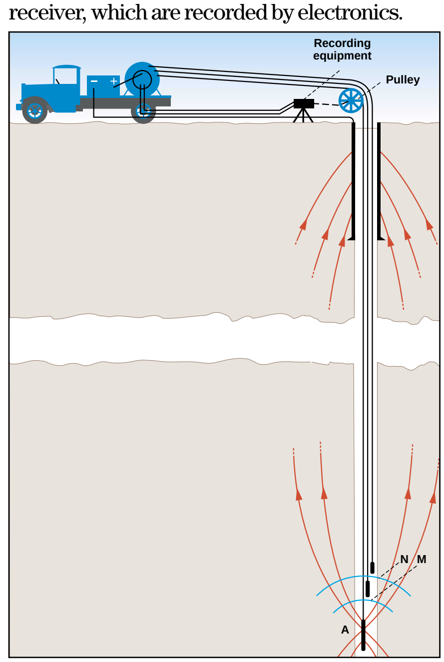

Figure 2. Resistivity logging employs an electrode (A) to generate currents M and N. From measurements of the potential difference between M and N, and the strength of current A, the apparent formation resistivity is calculated.

The amplitude of the signal relates directly to porosity, and the signal relaxation time relates to the size of the pore spaces containing fluids, providing an indication of permeability. NMR is a fluids-only measurement; however, due to the interactions of the pore fluids with rock surfaces, the rock matrix can significantly influence the fluid response.

The technology has existed since the early 1960s, but it has taken several decades to refine the process, with Numar – now a Halliburton subsidiary – the first to bring a continuous NMR logging tool to the market. The result has been an offering of tools and associated products that provide better depth of investigation and more information than ever before while traveling at the same pace as a traditional triple combo.

Pipe-conveyed logging

For at least two decades, highly deviated holes have required loggers to run their suites of tools on pipe. Initially those efforts took the form of traditional logging tools run on coiled tubing with electric line run inside the tubing. Almost instantaneous information received continually at the surface – now known as logging-while-drilling (LWD) and measurement-while-drilling (MWD) – while the well was being drilled had always been a goal. That goal was within range of the sophisticated logging tools by the advent of the combination tools in the early 1960s.

The barrier to earlier implementation of MWD and LWD was not the logging tools but the method by which to send the information to the surface while drilling with jointed pipe. As it turns out, a key advance in logging tools was not another logging technology but rather mud-pulse technology, which allows near-continual transmittal of logging information from tools on the bottom of the drillstring to processors at the surface through measurement of short, varying variances in mud pressure created by a component of the logging suite downhole. It is possible to employ almost any logging suite combination on the bottom of drillpipe and log the hole as it is drilled. While some operators remain reluctant to allow decisions on a well to be made solely on MWD/LWD logs, reliability and correlation have improved dramatically. E&P

This formation density tool was a major innovation in early nuclear logging technology.

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