02-017

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2002

03-25-02

State of New MexicoEnvironmental Department
2906 Rodeo Park Drive East
Santa Fe, NM 87505

PH. (505) 428-2544
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Mr. Steve Pullen

Thank you for your inquiry regarding running logs on some Monitor wells at Triassic Park Landfill East of Roswell, NM. The wells will be about 120' in depth and you will plan to run 4" PVC casing inside of a larger well bore. The annulus will be filled with some combination of sand and grout. You will be looking for some way to monitor these wells for any leakage of contaminants from the landfill. We talked about the Neutron log, along with the Natural Gamma Ray, as the best single log to run and the possibility of running the Induction Log as well.

We have logged several wells at this same site for Jim Bonner and I will gather some data on the logs we ran there before, some information on the tools themselves, and some results of our data . Mick is out of town this week and I have not found any of his reports as yet. I have some data I will forward to you and will have him contact you when he returns.

Call if you have any questions.

Sincerely ;

Don Pearson

D.E. Pearson - President

Probe Specifications

The probes utilized by Southwest Geophysical Services, Inc. are calibrated using standards supplied by the probe manufacturers. If true calibrations to known models are needed, the test pits at the Denver Federal Center are available. Project objectives should determine the method of calibration and standardization, with operating costs reflecting the method chosen.

E-Log

Measures:	SP 16 and 64 inch Resistivities Single Point Resistance
Manufacturer:	Mineral Logging Systems (MLS)
Length:	7 feet
Diameter:	2 inches
Depth of Investigation:	13 to 14 inches for the 16 inch Normal 50 to 60 inches for the 64 inch Normal
Vertical Resolution:	The bed boundaries have to be three to five times the Normal tool's spacing.
Use:	Correlation of bed boundaries Saturation Grain size
Calibration:	Test box with 0 and 100 ohm-m, mV settings Surface module with 0 and 100 ohm-m, mV settings
Operating Environment:	Fluid filled, open borehole

Caliper

Measures:	Borehole Diameter 1 and 3 arm tools
Manufacturer:	Comprobe or MLS
Length:	4 to 6 feet long
Diameter:	1 & 1/4 or 2 & 1/8 inches
Depth of Investigation:	Borehole wall (1.5" to over 8 feet)
Use:	Borehole diameter and rugosity
Calibration:	Physical diameter measurement
Operating Environment:	Fluid filled or dry borehole, open or cased

Neutron-Gamma Ray

	Thermal Neutron-Neutron Scintillation Gamma Ray
Manufacturer:	Comprobe or MLS
Length:	7 feet
Diameter:	1 & 1/4 or 1 & 11/16 inches
Depth of Investigation:	Neutron: 13 inches or 16 inches Gamma: 12 inches
Use:	Correlation of bed boundaries Saturation Porosity Lithology
Calibration:	Neutron: Fiberglass sleeve induces 1000 API counts, which is equivalent to 19% porosity in a 7 & 7/8 inch borehole saturated with fresh water Gamma: 120 API unit standard
Operating Environment	Fluid filled or dry borehole, open or cased

Sonic (Acoustic)

Measures:	Travel Time Amplitude Variable Density Log
Manufacturer:	Mount Sopris Instruments
Length:	9 feet
Diameter:	1 & 9/16 or 2 & 3/8 inches
Depth of Investigation:	6 inches
Use:	Lithology and porosity determination Saturation Correlation
Calibration:	Internal tool calibration sequence for 0 to 200 microseconds per foot and 0 to 100 mVolt amplitude deflections
Operating Environment:	Fluid filled open or steel cased borehole

Compensated Density

	Gamma-Gamma Density
Manufacturer:	Comprobe
Length:	11 feet
Diameter:	2 & 1/8 inches
Depth of Investigation:	3 to 4 inches
Use:	Bulk density for lithology and porosity determinations Bed boundary correlation
Calibration:	Aluminum (2.62 g/cc), Magnesium (1.735 g/cc), and Acrylic (1.28 g/cc) standards
Operating Environment:	Fluid filled or dry borehole

Temperature

Measures:	Temperature gradient of borehole
Manufacturer:	MLS
Length:	6 feet
Diameter:	1 & 1/4 inches
Use:	Borehole temperature
Calibration:	Certified mercury thermometer
Operating Environment:	Fluid filled open or cased borehole

Camera (Portable)

Measures:	Color Visual Borehole Inspection
Manufacturer:	Marks Products, Inc.
Equipment:	Kevlar reinforced cable on a hand-operated winch 1000ft capability
Length:	18 inch and 10 inch cameras
Diameter:	1 & 1/4 or 2 & 1/2 inches
Depth of Investigation:	Borehole wall
Use:	Lithology Hole condition Casing inspection
Operating Environment:	Fluid filled or dry, open or cased borehole no greater than 1000 feet

Camera (Truck Mounted)

Measures:	Color Visual Borehole Inspection
Manufacture:	Laval Underground Surveys
Equipment:	Steel Reinforced Coax in truck mounted winch 4000ft capability
Lengths:	24 inch plus light-head
Diameters:	1 & ½ or 3 ½ Inches
Depth of investigation:	Borehole wall
Use:	Lithology Hole condition Casing inspection (Steel, Stainless, PVC)
Operating Environment	Fluid filled or dry, open or cased wells, mine adits

Deviation

Measures:	Uses accelerometer and magnetic compass with respect to magnetic North Borehole direction Borehole Inclination
Manufacturer:	Owl Technical Associates
Length:	4 feet
Diameter:	2 inches
Use:	Determine verticality and direction of borehole
Calibration:	True vertical, changing direction while maintaining inclination, and maintaining direction and inclination while orienting tool to 4 compass directions
Accuracy:	+/- 0.2 degrees inclination, and +/- 2 degrees direction
Operating Environment	Fluid filled or dry borehole

Induction

Measures:	Formation Conductivity
Manufacturer:	Geonics
Length:	6 feet
Diameter:	1 & 13/32 Inches
Depth of Investigation:	Maximum sensitivity at 11 inches Minimum sensitivity at 4 inches
Vertical Resolution:	25 inches
Use:	Lithology
Calibration:	Test jig with known resistivities
Operating Environment	Fluid filled or dry open or PVC cased boreholes

Impeller Flowmeter

Measures:	Fluid Velocity
Manufacturer:	MLS
Length:	7 feet
Diameter:	2 & 1/4 or 3 & 1/2 inches
Use:	Fluid velocity and flow rate using volume balance from wellhead flow rate
Operating Environment	Fluid filled borehole Best results are seen when velocities are greater than or equal to 20 feet per minute

Fluid Sampler

Measures:	Given amount of fluid (1.4 liters, 1gal)
Manufacture:	MLS
Length:	3 feet
Diameter:	1 ½ inches
Use:	Fluid collection up to 5000ft
Operating Environment	Fluid filled borehole

Televiewer-Fac-40

Measures:	360 deg. Borehole Fracture orientations, Travel time, Amplitude Borehole deviation
Manufacture:	Advanced Logic Technology Sarl
Length:	2 meters
Diameter:	40 mm
Use:	Borehole imaging of wells from 44 mm to 400 mm in size Lithology, Hole condition, Casing inspection
Operational Environment	Fluid filled borehole
Orientation:	3-Axis Magnetometer, 2 accelerometers
Max Temp	70 deg. C
Max Pressure	160 bar

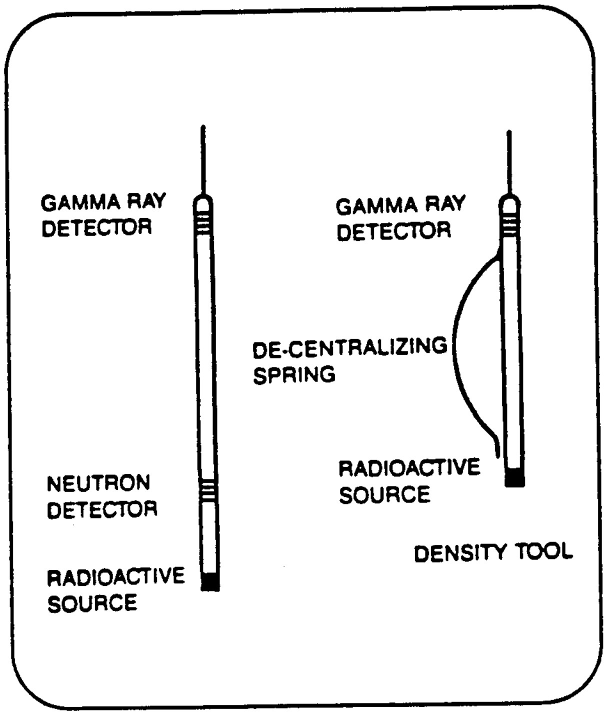
Chapter 3 | NUCLEAR LOGGING

Nuclear logs are related to the measurement of fundamental particles or radiations from the nucleus of an atom. The most common logs are natural gamma ray, neutron and gamma-gamma or density logs. Nuclear logs may be run in a variety of downhole environments in either open holes or cased holes.

Since the radiation measured in nuclear logs is random in nature, minor fluctuations are present on all logs, and the logs will not repeat exactly. Repeat logging runs are a positive means of separating random changes from deflections related to lithology. Figure 3-1 shows a combination gamma ray-neutron tool that may be used to record either log separately or both logs simultaneously. Also shown is a density tool of the type commonly used in water and mineral exploration.

GAMMA RAY LOG

Gamma ray logs measure the naturally occurring gamma emissions from the formation surrounding the borehole. These emissions are electromagnetic radiations that are released by a nuclei of an unstable element, decaying to a more stable state. In nature, the most significant of these elements occurring in abundance is potassium 40 (K40), uranium 238 (U238), uranium 235 (U235) and thorium 232 (TH232). The most plentiful of these elements is potassium 40.



Schematic-Nuclear Logging Tools

Figure 3 - 1

As the unstable element decays, issuing electromagnetic radiation, the gamma ray probe detects the events by recording the number of particles or photon emissions. This detection is accomplished by use of a sodium iodide crystal optically coupled to a photomultiplier. As the incident photon enters the crystal a release of energy takes place in the form of illumination that is detected by the photomultiplier. A corresponding voltage is delivered to the surface where it is counted and averaged over a specific time period. Since radiation is of a statistical nature it is necessary to average the measurement of radiation over a selectable time period in order to derive a representative sample of the amount of radiation being emitted.

The greater the counting rate the more events the gamma detector is measuring, which in turn corresponds to the greater amount of an unstable element present in the formation. As mentioned, potassium 40 is by far the most abundant of these elements found in rock strata. K40 is found in all potassium bearing minerals such as potassium feldspars, biotite, orthoclase and several clay minerals rendering detection of these minerals possible via the gamma ray log. Consequently, as the content of these minerals increases with the rock strata the response of the gamma ray probe increases. Inversely, as the content of the clay mineral decreases the response of the gamma ray probe decreases. Gamma ray logs show decreasing strengths from shales and clays, to siltstones, to sandy siltstones, to clean sandstones and gravels.

Dependent on how clay is present within the quartz matrix, as dispersed particles, structural grains, or as laminations, both porosity and permeability of the rock will be affected. To arrive at accurate porosity readings one must know the fraction of clay volume to total rock volume.

Clay Fraction = Clay Volume/Total Rock Volume

The gamma ray logs is often used to determine fraction of clay, when clay minerals contribute to a significant response on the log. an example is the mineral illite. The formula for deriving clay fraction is:

$$\text{Clay fraction} = (GR - GR_{cl}) / (GR_s - GR_{cl})$$

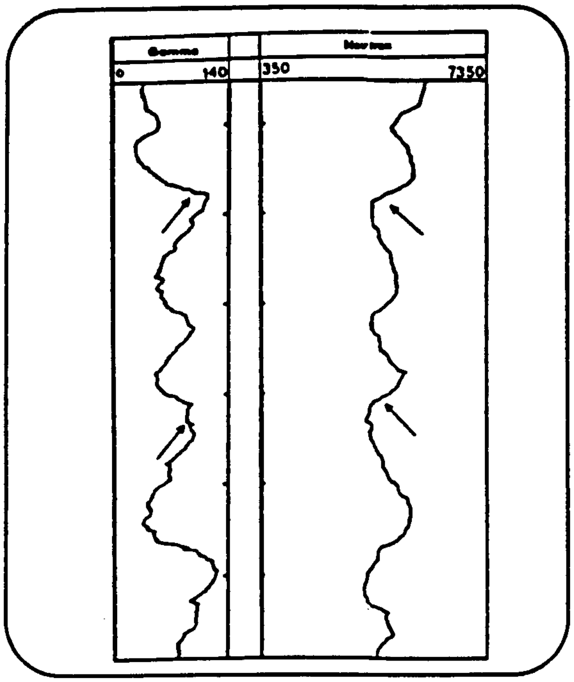
Where:

GR = the zone of interest
GR_{cl}= clay bed
GR_s= clean sand bed

A word of caution with regards to calibrating the log response, when the area of interest is near a clay bed, is the assumption that the area of interest contains the same clay mineral. While potassium and thorium are considered good clay indicators, uranium may be present in the rock strata that contains no clay, causing a false indication. Montmorillonite has little or no gamma ray response.

When gamma active clays are present, a gamma ray log can be useful in revealing stratigraphic development. Figure 3-2 displays a sloping gamma response that is corresponding to changes in grain sizes. The fining trend is upwards. This log response can be revealing and easily identified.

When logging in metamorphic and igneous rocks of low porosity, the gamma ray response is dependent on the minerals within the rock. The one exception being along open water bearing fractures where high gamma activity is recorded. This response is derived normally from either uranium which has become water soluble



Gamma-Neutron Log
Showing Upward Fining

Figure 3 - 2

under acidic conditions, or the alteration of the host rock by water movement that has precipitated radioactive enriched minerals along the fracture wall.

Because the gamma ray log is a passive measurement of naturally occurring radioactive elements, and being lithologically dependent, it is an excellent correlation log. Gamma ray logs are normally run with all porosity tools and with an electric log when SP response lacks definition.

The vertical resolution of the gamma ray probe is a function of counting, time constant and logging speed. When all three are at optimum settings the vertical resolution is approximately one foot. Because of the statistical nature of radiation emission, repeatability of the log is not exact with respect to statistical variation of the counts. For this reason, the log will show repeatability in the shape of the curve but the individual curve peaks may be slightly different.

Since the energy of gamma emission is inversely proportional to distance, the greater the borehole diameter the less effective the gamma ray log response. Gamma ray logs can be run in gas filled holes of either open or cased wells.

NEUTRON LOG

The neutron log, like the gamma ray, measures radioactive properties. Unlike the gamma ray, this log depends on the bombardment of the formation with neutrons from a source and measures secondary results brought on by this bombardment. As a comparison, the neutron log is like a resistivity log that measures the result of something being introduced into the formation, while the gamma ray and SP logs measure naturally occurring phenomena.

The heart of a neutron logging tool is the radioactive source that emits epithermal neutrons. Characteristically, the source is made of Americium 241-Beryllium with a strength of from 3 to 5 curies, which generate 2.2×10^6 neutrons per second per curie. Americium 241 has a half life of 458.1 years and a specific activity of 3.24 Curies

ATOMIC NO.	ELEMENT	CROSS SECTION IN BARNS CAPTURE	SCATTERING
1	Hydrogen	0.30	20.5
2	Helium	0.0	1.5
3	Lithium	64.0	2
4	Beryllium	0.009	6.1
5	Boron	7000	3
6	Carbon	0.0045	4.8
7	Nitrogen	1.75	10.0
8	Oxygen	0.0016	4.1
9	Fluorine	0.01	4.1
11	Sodium	0.5	3.5
12	Magnesium	0.4	3.6
13	Aluminum	0.23	1.5
14	Silicon	0.25	1.7
15	Phosphorous	0.31	10.0
16	Sulphur	0.53	1.5
17	Chlorine	33.0	10
18	Argon	0.62	1.9
19	Potassium	2.2	1.5
20	Calcium	0.43	9.5
22	Titanium	5.2	6.0
23	Vanadium	5	8
24	Chromium	3	4
25	Manganese	12.2	2.4
26	Iron	2.5	11.0
27	Cobalt	33.0	5.0
28	Nickel	4.4	18.0
29	Copper	4	8
30	Zinc	1.25	4.2
48	Cadmium	2500	5.3
50	Tin	0.69	5
51	Antimony	4.7	4.2
53	Iodine	6.8	3
56	Barium	1.25	8
74	Tungsten	16	5.7
78	Platinum	10.8	12
79	Gold	94.5	5
80	Mercury	425	15
82	Lead	0.2	13
83	Bismuth	0.02	9.2
90	Thorium	6	10
92	Uranium	2	8.2

Table 3-1 **Cross Section for Neutron Capture and Scattering**

per gram.

Once a neutron is separated from the source, it begins its travel through matter. Since it is neutral, it will lose energy upon collision with the nuclei of other atoms. After a sufficient number of collisions with nuclei and resulting loss of original kinetic energy, the neutron is slowed to a slow or thermal state. Although a formation's ability to slow down neutrons is considerably affected by its hydrogen content, this process is usually not free from the influence of other elements. An atom's comparative slowing down power to neutrons, in terms of the number of collisions required to thermalize fast neutrons, will decrease with increasing atomic number in proportion to the ratio of the two atomic numbers of the two atoms being compared. The capture cross section or probability that a neutron will interact with a nucleus depends upon neutron energy, size, mass and character of the atomic nuclei. Table 3-1 shows atomic numbers and

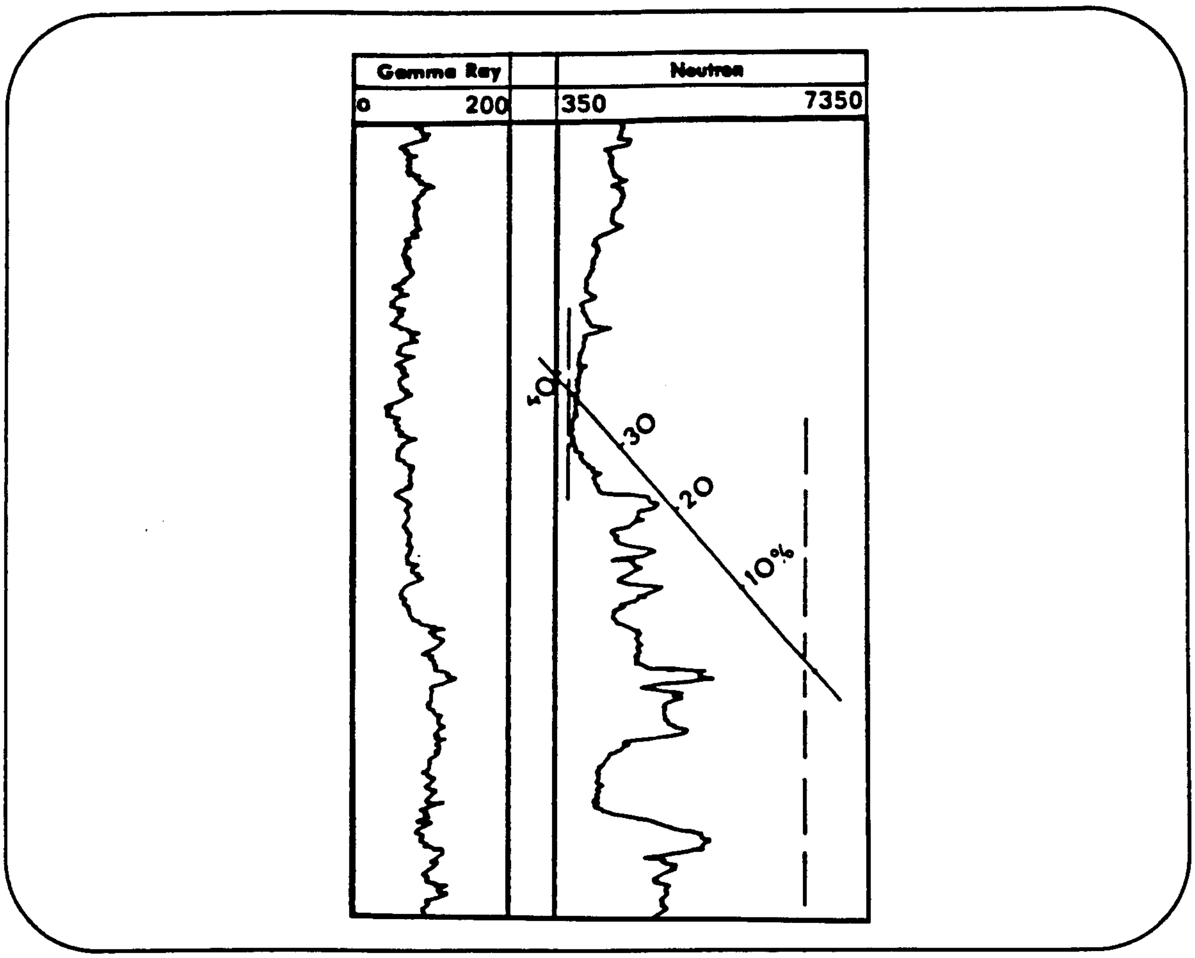


Figure 3-3 **Porosity Estimating Using Gamma - Neutron Log**

capture cross sections for some common elements.

Two different types of logging systems are employed in the running of neutron logs. These are the neutron-gamma log and neutron-neutron log. Early logging tools all used the neutron-gamma method of logging whereby the secondary gamma rays emitted during neutron capture were measured by a fairly insensitive gamma detector located a short distance from the source. The detector was kept small and insensitive so that is would react to little influence from the natural gamma radiation from the formation while responding to the wealth of the secondary gamma rays. Most present day neutron logging tools are of the neutron-neutron type. This system uses a Helium 3 detector about six inches long that responds to thermal neutrons as they pass through the detector after being slowed by collision with nuclei in the formation. This passage ionizes the detector gas and causes a pulse which is electronically processed within the tool and sent to the surface.

All the quality logs are calibrated to standards set out by the American Petroleum Institute and are recorded in API Neutron Units. Calibration is accomplished by placing the tool, while attached to the logging cable, into an environmental calibrator that duplicates the conditions and porosity of the API test pit at the University of Houston.

The prime advantage of the neutron log lies in the fact that it is a reliable indicator of porosity of reservoir rocks, It has been proven that the response of the neutron curve is empirically related to the hydrogen content of rocks and that the hydrogen content of liquids in pore spaces can be accurately related to porosity in most cases. Figure 3-3 has a neutron log in the right hand track that has a porosity scale superimposed on it. Rock samples taken while drilling tend to confirm the reliability of the plotted scale.

DENSITY LOG

The density log represents the electron density of the formation. By virtue of this, porosity can be determined along with lithologic identification, gas detection and clay fraction when used in conjunction with other porosity tools.

The density probe design is similar to the gamma ray probe in that the downhole circuitry contains a gamma detector. In the case of a compensated density probe there are two detectors. This detector, with the use of a back-up arm or spring, is pushed against the borehole wall. A radioactive source, located some distance and on the same plane as the detector, bombards the formation with intermediate gamma ray energies. The phenomena of Compton scattering takes place in which back scattered gamma rays are received by the detector, or detectors.

Compton scattering is the elastic collision of gamma rays with orbiting electrons. Upon collision the gamma ray and electron change both direction and velocity. Compton scattered gamma rays are therefore proportional to electron density of the formation. electron density is closely related to bulk density since true density is the mass number, A, which is the total number of neutrons and protons within the atom. To calculate true density when electron density is known, it is necessary to know the ratio of Z/A.

Density derived porosity is calculated from measured bulk density.

$$p = p_{ma}(1-P) + p_{fl} x P$$

or, $$\phi_{PD} = \frac{p_{ma} - p_b}{p_{ma} - p_{fl}}$$

where;

ϕ_{PD} =density derived porosity

p_m =density of matrix

p =log derived density

p_{fl} =density of mud filtrate or pore fluid

As mentioned, density logs are often used to derive a formation porosity, P, defined as the ratio of pore volume to total volume of rock. Within intergranular rocks, porosity is the void space between grains, intragranular porosity is the void space within the grains, and vugular or fracture porosity is often considered secondary porosity.

Within a given matrix value, as the p of the equation changes there is a corresponding change in the porosity. Often a matrix value is assumed for a single mineral and if that value changes within the formation, an erroneous porosity will be given. A formation may contain more than a single mineral, necessitating caution in choosing a matrix, or obtaining a core derived density matrix. For example, if the matrix value was assumed to be 2.65 gm/cc and the log derived density was 2.50 gm/cc, the porosity would be given as 9.09 percent. If the actual matrix value was 2.60 gm/cc then the porosity would be 6.25 percent, a difference of 2.84 percent.

Density log response is also used for mineral identification when run with other porosity devices. Each porosity device responds to a particular mineral in quite different ways, which when cross-plotted can often identify the mineral. If only one porosity device is used, however, then it is extremely important to cross-correlate that log response to the other available logs. For instance, a density log run alone might often be unclear in distinguishing shale or clay, from sandstones since both rock types have similar densities. The use of a gamma ray log should help in the definition. Like the neutron log, the density logs basically see total porosity, where a false porosity would be derived if the rock were vugular. If a sonic log is available, the porosity can be corrected since sonic energy is thought to avoid the vugs and fractures, by traveling through the matrix instead, the path of least resistance.

The density probe can be run in either water or air filled holes. By virtue of being a sidewall contact probe, the density tool is considered to have good vertical resolution. Vertical resolution is a function of the source to detector spacing, the time constant for averaging the counts and the line speed. If an appropriate time constant and line speed are maintained, the vertical resolution is equal to approximately half the distance between source and detector.

The compensated density probe,

employed by the most service companies, consists of two detectors located on the same plane as the radioactive source. As the name implies, compensated density probes are designed to reconcile inaccurate densities due to borehole conditions. As the density probe rides the borehole wall it is influenced by the condition of that wall. In a rugose hole the single detector, if not entirely pushed against the borehole wall, will average the densities of either the air or borehole fluid with that of the formation. False densities can also be logged due to heavy mud cake. The compensated density probe employs two detectors, one near the radioactive source which is influenced by mud cake and tool standoff, and a far detector which is mainly influenced by the formation. The counting rates of both detectors are plotted against each other for known densities at zero gap, and then for fluid densities greater than formation density, and fluid densities less than formation density. Essentially, the compensated density probe is designed to eliminate borehole conditions in order to derive actual formation densities.