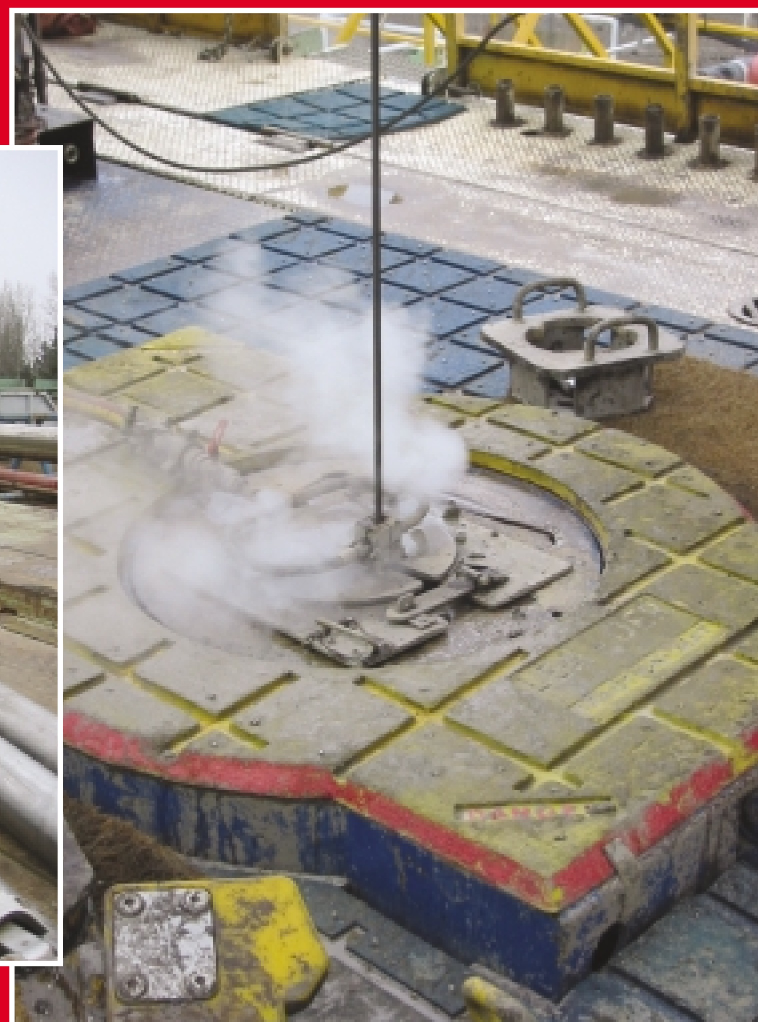
InSite

CWLS Newsletter

JUNE 2004



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Cover Photos: *A line stripper with steam hose used to clean the wireline as it comes out of the wellbore. Photo Courtesy Robert Bercha.*
Logging tools on the catwalk. Photo Courtesy Robert Bercha.

If you have a photo that the CWLS can use on it's next InSite cover please send a high resolution jpeg format version to Robert_Bercha@anadarko.com or meddy@wellsitegas.com. Include a short description of the photo with your submission.

President's Message

In the last issue I solicited input on what the Society could be doing. Via e-mail, dozens of people came forward with ideas. Three of these suggestions stood out in that they did not involve Nigerian banks. They were:

- Make all of our past publications available in a digital format. (Ross Crain)
- Revitalize LAS 3.0, possibly tying it in with a plotting standard that together would store enough information to digitally recreate an entire log. (Kenneth Heslop)
- Identify and approach recognized experts in various aspects of formation evaluation to see if they would be available to present luncheon talks with subsequent workshops, seminars or short courses.(Bob Everett)

I would like to thank these people for taking the time to put forth these ideas. The CWLS Executive is moving ahead with all of the suggestions.

On behalf of the Executive I would also like to thank all of the CWLS members who volunteered their time at the recent ICE Convention.

Jeff Levack, CWLS President

Editor's Note

This will be the second issue of InSite in 2004. The price of oil is currently at record highs and break-up is drawing to a close. The summer drilling season is looking to be as busy as it was during the first part of the year. Service companies are catching up on maintenance while E&P companies are flanging up their summer drilling programs.

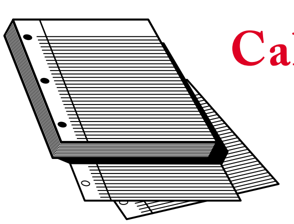
Are the high oil prices we are seeing currently a glimpse of the future? Based on an estimate by the USGS the peak of world oil production may occur on or around 2040. If production from the Middle East is removed from this estimate it may occur as soon as 2023 for the rest of the world. With our society's current dependence on hydrocarbons, the importance of Canada's vast oil sands deposits (1.6 trillion barrels of oil equivalent) will increase. Also petrophysical analysis will take on a new level of importance as the search for previously unidentified/by-passed accumulations continues.

We have a number of authors this time who have provided interesting articles for your reading enjoyment. For the first time we have decided to re-print an SPWLA paper written by Darwin Ellis. Darwin is the inventor of the LDT and his paper naturally has to do with density porosity. We think that you will find this paper both interesting and educational. Accurate estimations of porosity are a key part of understanding any reservoir.

The second paper is about the importance of properly catching cutting samples while drilling. It explains why and how to catch quality samples. Originally written for rig crews, this article reminds us of the value of accurate sampling and shows how easy it is to obtain a poor quality sample. The viability of the well being evaluated and future development of more wells in the area can be affected by the sample quality. Why is it that one of the least technical people on the lease is responsible for what may be the most important information we get while drilling the well.

Enjoy.

Robert Bercha
Mike Eddy
CWLS Publication Co-Chairmen



Call for Papers

The CWLS is always seeking materials for publication. We are seeking both full papers for the Journal and short articles for the Newsletter. Please share your knowledge and observations with the rest of the petrophysical community. Please contact publications co-chairs Mike Eddy (meddy@wellsitegas.com) at (403) 230-0630 or Robert Bercha (robert_bercha@anadarko.com) at (403) 231-0249.

As the Winch Turns

Teaching Well Logging and Formation Evaluation for Petroleum Engineering Students – A Tough but Necessary and Rewarding Job

One of the most common complaints related to newly graduated petroleum engineers is that "they do not know how to interpret a log". Some will even say that "apparently they never saw a log before".

There are a number of circumstances that contribute to this lack of knowledge: Engineering programs tend to put much more emphasis on other disciplines, such as reservoir, drilling and production. Also many students tend to consider the subject boring and with no usefulness at all for young field engineers. Unfortunately, the plain fact is that it is not uncommon to have junior professionals with a noticeable lack of understanding on the basics of well logging and formation evaluation.

Last year, after 25 years in the oil industry I made a career change and became a professor at the University of Alberta. Due to my oil patch experience I was asked by the department head to teach a course on "Well Logging and Formation Evaluation".

One of the first reminiscences that crossed my mind was of my first year as a field drilling engineer, when I would many times sit beside a geologist and a logger from a service company and listen to their discussions about logging results. On those occasions I would do my best to display an interested expression and pretend an understanding that, by that time, I did not have. It took me a few years and a lot of patience from some colleagues to finally be able to sit with them and really have something useful to say.

I decided that I should at least try to give to my fourth year students a good understanding of the principles and applications of log interpretation. I figured that a good source for information would be oil & gas companies and service companies.

I started contacting some of the major logging companies to get permission for student access to the premium content on the company's websites. Most companies have a premium content that is reserved only for clients and employees. Some companies will grant access to professors and students from registered universities. By granting access to the valuable content of these non-public websites, the students have the opportunity to consult hundreds of articles, books, tool catalogues and online simulators and calculators. This has proven to be fundamental to the students understanding of the discipline and the industry.

In an attempt to bring a more practical approach to the classroom, I invited speakers from the industry to come and talk about a specific tool, operation or log interpretation.

One aspect that was very challenging was to find actual logs to be presented and discussed with the students. Logging results are almost always confidential (at least on newer wells) and are not shared. This issue was overcome with a few logs obtained from oil companies and also with logs available online on some North American public databases. None-theless it remains one weak point of the course.

Another approach that proved to be very efficient was to divide the students into small groups and assign to each group a paper relating field cases and practical problems on well logging and formation evaluation. Each group would write a report about the article and subsequently present it to the entire classroom. The benefits and advantages of this type of assignment when compared with the regular homework were evident.

Evaluation from the students attending the first course was very encouraging. Most of them have graduated and are now part of our industry. A new course will be offered this coming Fall, 2004.

JC Cunha, Ph.D.
Associate Professor of Petroleum Engineering
School of Mining & Petroleum
University of Alberta
E-mail: jc.cunha@ualberta.ca

Editors Note: JC is looking for companies/Individuals to participate or contribute to UofA's "Well Logging and Formation Evaluation" course. If you are interested, please send an e-mail to jc.cunha@ualberta.ca. He is looking for companies to provide a professional that can come to the UofA and speak for 1-2 hours to the students about general or specific subjects related to the company's activities, tools, wireline logging, LWD, logging interpretation, etc. Also, if you have non-confidential sets of logs (in paper or electronic files) that you would like to contribute to the educational process, he would appreciate it. Please forward them to him at the above address or e-mail so they can be used in the course. Public acknowledgment will be given to all companies in the classroom and also on the course website and notes.

CWLS 2004 to 2005 Executive

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Chair of Committees' Message

At any given time, our Society has a number of committees. These committees may be set up as new ideas or events dictate, or disbanded when they successfully accomplish their goals.

Currently we have six committees, the most active of which are:

Special Core Database: This committee was originally formed to coordinate the digitization of core data, such that interested parties would be able to access that information for a particular area or formation of interest. The Core Database is a work-in-progress, and this committee is always expanding the available data and making it easier for members to access.

Student Awards: Every year, the CWLS presents one or more grants to promising candidates who are enrolled in an educational facility and researching a topic which promotes the role of logging-related subjects in the oil and gas industry. The Student Awards committee advertises the awards to interested students, and evaluates the submissions before making their recommendations. The scope of this committee has recently been broadened by renaming it the Student Liaison Committee – in addition to the awards mentioned above, the committee is now responsible for overall communications between the CWLS and various institutions to create awareness of the role that well-logging plays in the industry.

LAS and Digital Graphics: We have a LAS Committee and a Digital Graphics Committee, which are responsible for designing and improving the ways in which log data is moved digitally. Sometimes, as now, these committees work together to investigate ways in which data and graphical images can be combined for storage and transmission.

Other committees are established as necessary to coordinate one-off events, such as the past CWLS/CSPG Convention.

The role of the Chair of Committees is to help the committees function by conscripting volunteers, by encouraging the committees to move forward, and to act as a bridge between the individual committees and the CWLS Executive. I keep an ongoing list of people willing to volunteer – if you would like to join in, please contact me!

Richard Bishop
Chair of Committees

Attention Software Professionals

The Canadian Well Logging Society is seeking expressions of interest from software professionals. We wish to upgrade our current Adobe/Excel formatted water resistivity catalogue. Our goal is to be able to provide users with web-based access to a database of water resistivity values for Canada and North Dakota.

Each data point includes:

- Layer Number
- Well Name
- Top Formation Depth
- Base Formation Depth
- Latitude
- Unique Well Identifier
- Top Formation Name
- Base Formation Name
- Longitude
- Rw

The functionality should include:

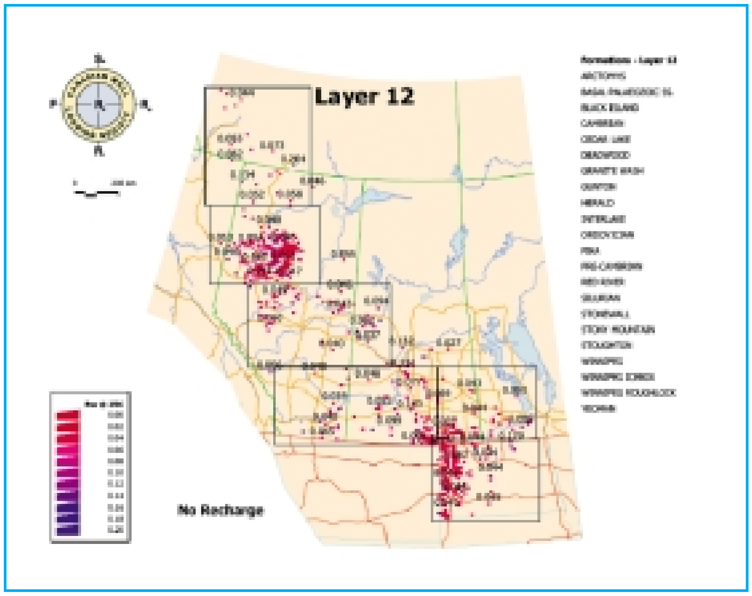
- Graphical user interface based on a map of Canada and North Dakota
- Work flow that requires user to select a formation name from a list before points appear on the GUI
- Availability of data for a particular location indicated by dot on the map
- Rw for a particular location indicated by dot colour
- Ability to zoom from full country to single LSD
- Ability to see all data for a point by clicking on it on the map
- Ability to select an area on map and create a list of all data points in that area

For more information or for an example of the current dataset please contact Jeff Levack at 403-232-1705.

New Members

Carter Clarkson - Hycal Energy Research Labs
Barry Clattenburg - CL Consultants Limited
Jinyi Zhang - Baker Atlas
Bryan Hartall
Robin Zubach - Core Laboratories

2002 CWLS Rw Catalog



Information included on CD:

- 2002 Rw Catalog
  (Over 50,000 Data Points)
  - PDF Format
  - Spreadsheet (XLS) Format
- 1987 Rw Catalog
  (5,600 Data Points)
  - PDF format
  - Original "Data on Disk" Digital Format
- LAS 2.0 and 3.0

Prices (Shipping Not Included):

Members:	$25.00 CDN (limit one per member, two per corporate member)
Non-members:	$65.00 CDN

Network License (corporate members):	$500 CDN
Network License (non-members):	$1000 CDN

To order contact the CWLS office at (403) 269-9366.

A high resolution copy of the latest newsletter is posted on the CWLS web site at www.cwls.org. For this and other information about the CWLS visit the web site on a regular basis.

Please forward this newsletter to any potentially interested co-workers. We would appreciate any feed back on anything you've read in the InSite and any suggestions on how this newsletter can better serve the interests of the formation evaluation community. Feel free to contact anyone on the CWLS executive with your comments.

Rotary Well Samples

By Charles A. Engen B.A., B.Sc. ECL Canada Ltd.
Photographs Courtesy R. Bercha and G. Gorman

A rotary well is deepened by the action of the rock bit upon the surface of the rock being drilled. As the bit turns, it crushes or pulverizes the rock formation into very small pieces called cuttings. Rock cuttings are only 3 millimeters (1/8 inch) or less in diameter. The geologist examines these cuttings under a microscope and provides a description of them in his striplog.

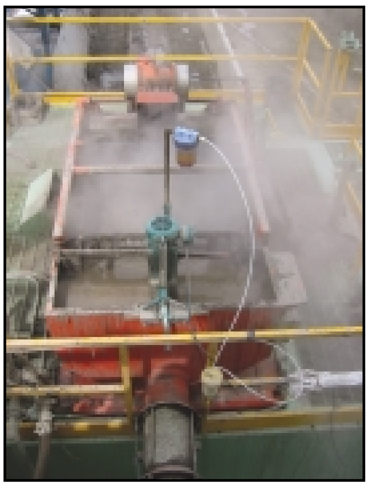


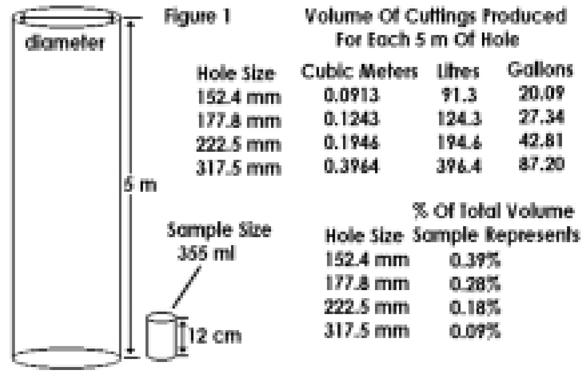
Photo 1: Typical shale shaker. Courtesy R. Bercha

The geologist is limited by the quality of the samples he is given, which makes the job of the person catching the samples very important. The job of sample catcher is not considered very 'glamorous' amongst most drilling crews, and therefore is often relegated to 'second place' in a list of tasks. However, it is important to remember that a well is being drilled because of geology, not because an engineer wants to. It only makes sense that the job of the sample catcher, and the quality of the samples that are caught are also very important! It follows that the person catching/processing the samples fully understands his/her job and the consequences of doing less than a good job.

Samples are usually caught in 5-meter intervals, which are named (labeled) for the bottom of the interval concerned.

That is to say, the 450 m sample represents the rock drilled from 445 to 450 meters; the 455 m sample represents the rock drilled from 450 to 455 meters and so forth. As five meters of hole are drilled, the rock cuttings, are continuously carried to the surface in the mud system to the shale shaker (Photo 1). At the shaker, the cuttings are separated from the fluid part of the mud, and discarded. It is during the process of discarding the cuttings that the geological sample is collected.

As can be seen in figure 1, depending upon the size of hole drilled, a certain volume of cuttings are freed into the mud system for each meter of hole drilled. In a 222 mm hole, for example, about 0.1946 m^3 of cuttings (about $1^1/4$ 45 gallon drums) are liberated into the mud for each 5 meters of hole drilled. It would be impossible to examine that amount of material. Instead, a small amount (a sample bag full), is examined. As may be seen in Figure 1, the size of a sample compared to the volume of cuttings drilled is very small. This is why it is important that the sample is collected correctly. Surprisingly, this is not as difficult as it may seem.



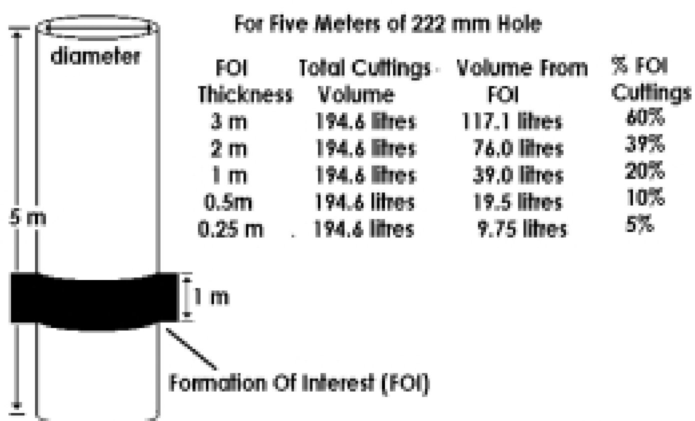


Figure 2

Figure 2 demonstrates the importance that what goes into a sample bag must represent all of the rocks drilled in each five meters. If, for example, a 1-meter thick zone in a five-meter section of hole is drilled, the amount of cuttings representing the formation of interest is only 20% of the total amount of cuttings drilled. If a less than perfect sample is caught, the zone of interest may not be represented in the sample at all. As is shown in Figure 2, the thinner the formation of interest, the more enhanced this problem becomes.

When a sample is caught off the end of the shale shaker (Figure 3), that sample may represent only 1% or less of the total rock drilled for that particular sample. Such a sample is usually useless for the geologist. There are, however, legitimate circumstances in which you may be asked to catch such a sample.

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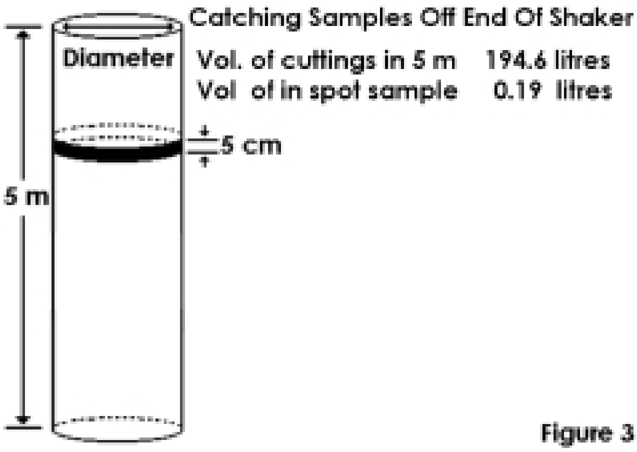

Simple Rules For Proper Geological Sampling.

1. Rock cuttings are only 3mm or less in diameter. Cuttings larger than this size tell the geologist nothing about what is being drilled, these are cavings from parts of the hole that have already been drilled. Cavings are material that falls into the mud system from the side of the wellbore. A sample bag full of cavings is hardly worth looking at.
2. It is important that samples be caught on time. The geologist should supply the rig crew with a list of appropriate lag times. When the depth of 675 m has been drilled, one lag time later the 675 m sample should be collected. A sample caught a minute or two late usually will not make much difference, but a sample caught 20 or 30 minutes late can make a big difference.
3. The sample must represent the entire 5-meter interval that was drilled. Thus the method of collecting the sample is very important. Usually a bucket is placed such that a small trickle of sample continuously goes into it (Photo 2). Ideally, when it is time to catch the sample, the bucket should just be nearing full. If the bucket fills quickly and overflows, the sample will again only represent part of the interval. The sample catcher then takes some sample from various depths in the bucket, washes and screens it (Photo 3, 4 & 5), and puts it into the sample bag. This is a proper sample. It is important to take some sample from the entire contents of the bucket, not just from the top or bottom. The bucket is then emptied out and repositioned to collect the next sample.
4. The geologist may collect a sample off the end of the shaker, or may ask the sample catcher to catch a 'spot sample.' In this case the geologist wants to see what is coming over the shaker at that particular moment. Usually this coincides with a peak on the gas detector or a change in the rate of penetration.
5. Be honest regarding the samples. If a sample was missed, then tell the geologist so. Just don't make a habit of it. Never try and 'fudge' a sample by collecting cuttings off the ground etc., the geologist usually can tell when this has been done.
6. At times the geologist may be less concerned about sample quality. There can be a number of reasons for this. When drilling is very fast in very thick shale sections, for example, the geologist will usually not be as concerned about sample quality. Pay attention to the geologist, he/she should always keep you informed about such matters.

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Photo 2: Bucket used to catch sample from shale shaker. Courtesy G. Gorman

Photo 3: Roughneck pouring sample into sieve for washing. Courtesy G. Gorman

Photo 4: Drill cuttings in sieve before washing. Courtesy G. Gorman

Rotary Well Samples *... continued from page 9*

7. If you have a question regarding the samples, ask the geologist. He would rather you ask a silly question than catch poor quality samples. An experienced geologist can easily tell how much effort is being put into sample collection from the size of the cuttings, how clean the sample is, and whether or not what he/she sees in the samples correlates with drilling rates and gas detector response.

Photo 5: Washed sample in sieve.
Courtesy G. Gorman

Photo 6: Prepared sample ready for vials.
Courtesy R. Bercha

C. Engen (Chuck) attended the University of Calgary receiving a degree in Archaeology in 1976 and a degree in Geology in 1982. He first worked as a mudlogger and then began working as a wellsite geologist in 1984. He has worked all over the world and is currently employed by ECL Canada Ltd. formerly known as Decollement Consulting.

Members can advertise here for $25.00/issue.

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Announcement - Talk is No Longer Cheap

Local talent has been under represented at our monthly technical luncheons. So, in addition to the usual President's Award for the year's best technical luncheon presentation there will be a new Vice-President's Award. This award, in the amount of $500, will be for the best luncheon talk by a Canadian-based speaker who is from an oil company or from a university or college.

Anyone who is considering presenting at a luncheon or who has a suggestion for an interesting topic should contact John Nieto at (403) 231-0276 or john_nieto@anadarko.com.

CWLS Cartoonist

Do you have a creative side? Do your friends think you are funny and you know how to draw? If you fit this profile this might be your big break. We are looking for an artistic, humorous individual to create a comic strip for each InSite with an oil patch twist. Please contact Mike Eddy at (403) 230-0630 or email meddy@wellsitegas.com or contact Robert Bercha at (403) 231-0249 or email Robert_Bercha@anadarko.com for the offical position as the CWLS Cartoonist.

CWLS Archivist

Rosalie McDonnell of Talisman Energy has volunteered to act as the archivist for the CWLS. The society is renting space at the Glenbow Museum to house and protect artifacts of interest to the CWLS. If anyone has anything they would like to donate please contact Rosalie at (403) 231-2973 or email her at rmcdonell@talisman-energy.com.

Wild buffalo in field office parking lot, Ft. Liard Area, NWT.
Photo Courtesy Brian McGregor

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- Post core, FT, test data, core photos
- Perm predictions
- Statistical models, multivariate, clustering
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- Las, ascii, dlis, lis in and out
- Win / PC based, cgm, pdf emf outputs

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or brian@nmrpetrophysics.com

Formation Porosity Estimation from Density Logs

Darwin Ellis[1]

INTRODUCTION

At some time early in your career someone thrust before you a log with multiple traces, maybe some in color, with various symbols, codings, or shadings. In your panic to not seem too ill informed or inexperienced maybe you looked at the log heading for some guidance and your eyes fell on a curve labeled PHID or ϕ_d or some other symbol or mnemonic that indicated "density porosity." This brief tutorial aims to present a simplified account of what lies behind such a trace of density porosity. If you are new to petrophysics this article will provide you with an overview of the measurement techniques, pitfalls, environmental conditions and other factors that you should be aware of when undertaking the interpretation of a density log in terms of porosity. If you are an "old hand" maybe you will just enjoy reading about something that you already understand.

The topics covered range from the link between density and porosity to the physics of gamma ray scattering devices commonly used for the borehole application, and the precision imposed on the measurement. The photoelectric factor (P_e), an auxiliary measurement that can assist identifying the host mineral, is discussed along with the operation and limitations of borehole measurement devices including modern multi-sensor and LWD devices. A final section on measurement quality examines the role of depth of investigation and the importance of rugosity effects.

DENSITY AND POROSITY

To estimate the porosity of a piece of rock, the measurement of its density is the most straightforward approach since there is a well-known and very appealing linear relation between density and porosity. In the case of a binary system of a framework of rock with a density ρ_{ma} and a portion of the volume filled with a fluid of density ρ_f it is given by

$$\rho_b = \rho_f\,\phi + \rho_{ma}\,(1-\phi)\,. \qquad (1)$$

In the preceding equation ρ_b is the bulk density of the formation and ϕ, the porosity, or volume fraction that is not rock, or "matrix." It is assumed to be saturated with a fluid of known density. Defined in this manner, the porosity corresponds to what petrophysicists call "total" porosity, ϕ_t. Note that porosity is dimensionless (*v/v*) so it is often reported as a decimal between zero and unity. It is sometimes convenient to use porosity units (p.u. or percent) which is simply 100 times the volume fraction associated with porosity.

It's an easy matter to see that a density measurement can easily be translated into porosity; it's just a matter of scaling. Solving the first equation for porosity yields

$$\phi = \frac{\rho_b - \rho_{ma}}{\rho_f - \rho_{ma}} = a\rho_b + b,,$$

where the scaling constants a and b are not constants but depend on the formation parameters specific to the zone being investigated

$$a = \frac{1}{\rho_f - \rho_{ma}} \text{ and } b = \frac{-\rho_{ma}}{\rho_f - \rho_{ma}}.$$

Thus, to estimate porosity properly, two important parameters must be known: the rock matrix (or grain) density ρ_{ma} and the density of the saturating fluid ρ_f since they

Manuscript received by the Editor June 27,2003; revised manuscript received July 21,2003.
[1]Schlumberger-Doll Research, Ridgefield, CT USA
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TABLE 1 Typical ranges of matrix and fluid densities.

Density Ranges (g/cm^3)	
Fluids	ρ_f
Water	1.00
Salt Water	1.2 – 1.4
Oil/Condensates	~0.6 – 1.0
Gas	~0.4 or lower
Matrices	ρ_{ma}
Limestone	2.71
Dolomite	2.87
Sandstone	2.65
Anhydrite	2.96

determine the slope and intercept of this wonderfully simple relationship.

INTERPRETATION PARAMETERS

The first thing to remember when you see a curve on a log labeled "density porosity," such as in Figure 1 (where it is actually called DPHI), is that someone else has done an interpretation for you. They have chosen values for ρ_{ma}, and for the density of the saturating fluid ρ_f. These may be appropriate for your particular situation or not.

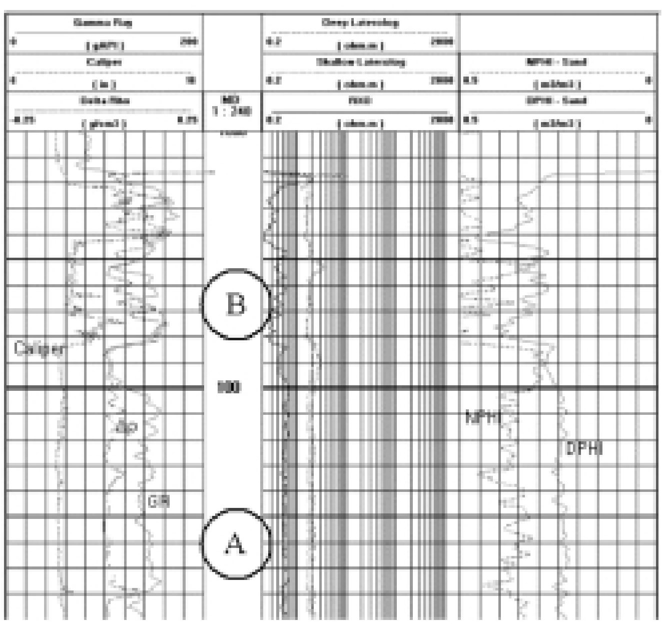

FIG. 1 Density log example. Track 1 contains the caliper, Gamma Ray and the correction curve $\Delta\rho$. Track 3 displays neutron porosity (NPHI) and density porosity (DPHI). Track 2 contains the usual three resistivity curves of differing depths of investigation. In zone B nearly all the traces show evidence of borehole rugosity or wash-outs.

TABLE 2 Range of porosity estimates (p.u.) for a formation of density 2.5 g/cm^3.

ρ_{ma} \ ρ_f	0.6	1.0	1.4
2.71	10	12.2	16
2.65	7.3	9.1	12

First of all, how important is it to choose the appropriate values of the matrix and fluid values? For typical sedimentary rock, theoretical values of matrix density range from 2.65 g/cm^3 for quartz to 2.96 g/cm^3 for anhydrite. The fluid density may range from 1.00 to ~1.4 g/cm^3 for water, mud filtrate or brine, depending on the salinity. In the case of light hydrocarbons the value could be as low as 0.6 g/cm^3 or much lower, as in the case of low pressure gas. Table 1 summarizes the density ranges.

To illustrate the effect of errors in fluid and matrix density on the accuracy of the porosity estimate, imagine a water-saturated rock (ρ_f = 1 g/cm^3) whose density has been determined to be 2.5 g/cm^3. If you are uncertain as to whether it is sandstone (quartz) or limestone (calcite) then its porosity is either 12% or 9%—an uncertainty that would be intolerable for making economic or engineering decisions.

Now, assuming a calcite matrix, let's look at the impact of the uncertainty in fluid density. If the saturating fluid is a very dense brine (1.4g/cm^3) then the porosity corresponding to the measured density of 2.5 g/cm^3 is 16%. On the other hand if the saturating fluid is a low density hydrocarbon of density 0.6 g/cm^3 then the corresponding porosity would be about 10%. Table 2 lists all possible values of porosity estimates, in porosity units, for a formation of density 2.5 g/cm^3 for some extremes of fluid and matrix densities.

The plots in Figure 2 summarize, at three values of formation density (2, 2.25, 2.5 g/cm^3), the approximate error in porosity when the matrix density and fluid density deviate from the nominal values used for the initial estimation of porosity (ρ_f = 1.0 and ρ_{ma} = 2.65g/cm^3 in this case). The error shown is in porosity units. At low porosity the influence of the fluid density error, shown in the left-hand plot, is relatively small but grows with increasing porosity. The converse is true for errors in the grain density, seen in the right-hand plot.

How accurate does the density measurement have to be? The answer of course depends on how well the porosity

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needs to be known. Since porosity is often translated into barrels and then into dollars, it perhaps makes more sense to assign an absolute value rather than a fractional value to the accuracy of porosity. For sake of discussion, a tolerable uncertainty on porosity is often taken to be 1% of volume fraction or 1 p.u. Using this standard, the results in Figure 2 can be used to determine how well the interpretation parameters need to be estimated.

Since the density is not measured with absolute precision, what are the tolerable limits? Let us use the same standard and require that the precision on the porosity must also be 1 p.u. By using nominal values for fluid and matrix density (to be precise 1.00 and 2.65 respectively) in equation (1) we can find the sensitivity of porosity to density by differentiating the expression which results in

$$\partial\rho = 1.0 \times \partial\phi + 2.65 \times (-\partial\phi) = -1.65\partial\phi.$$

This leads to the rule of thumb that a precision on the porosity of 1 p.u. requires a precision on the density measurement of ~0.0165 g/cm^3.

So how are reasonable values of matrix density and fluid density arrived at? In the case of matrix density, many petrophysicists feel that only core analysis can provide the correct value. Although the matrix density of a quartz sandstone is known, this type of idealized reservoir will rarely be encountered. Other minerals, including clay minerals, may be present causing the matrix or grain density to deviate, perhaps significantly, from the textbook value of 2.65 g/cm^3. In the case of carbonates it is common to have mixtures of limestones and dolomites/anhydrites in addition to the ubiquitous presence of clay minerals. In both cases the grain density needs to be determined from core, cross-plotting other logging measurements, the use of the photoelectric factor (to be discussed later) or perhaps from using a relatively recently developed interpretation (Herron and Herron, 2000) of the analysis of formation elements from gamma ray spectroscopy.

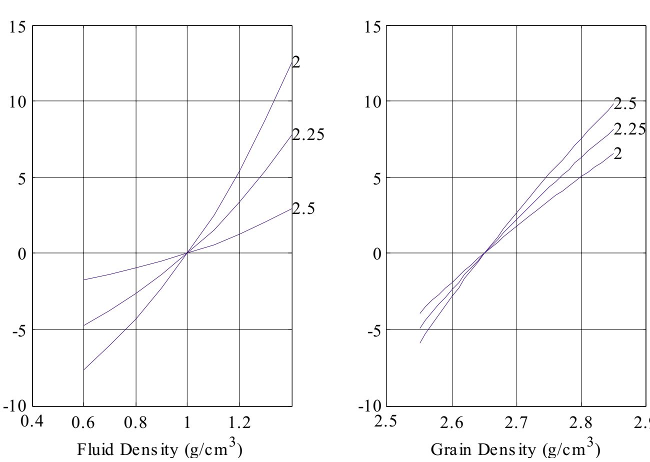

FIG. 2 A summary of errors in estimated porosity for errors in fluid density and grain density, evaluated for three values of formation density between 2.00 –2.50 g/cm^3.

The fluid density can often be taken as 1 g/cm^3 if the formation water salinity is not too elevated and if the mud system is fresh, since the fluid density in the invaded zone will correspond to the mud filtrate. However, in the case of logging while drilling, at a time relatively soon after the drilling when invasion has not proceeded to any great extent, the density of the formation fluid could be much different from the mud-filtrate density since the undisturbed formation fluids would saturate the formation. Interpretation difficulties would arise, for example, in a light hydrocarbon zone if the fluid density is routinely assigned to 1.0 g/cm^3.

Regardless of the complexity of the rock and fluid system (imagine a porous shaly sand saturated with residual gas and water) the simple linear density interpretation treats the system as binary. Some appropriate matrix density will characterize the partial volumes of the various minerals that make up the shaly sand and some intermediate fluid density will provide the best porosity estimate. The use of fall-back values for the two parameters may produce a useable first analysis, but combining the density with other measurements is the best way to determine the porosity. However, this is not a tutorial on multi-tool interpretation but rather on the determination of porosity from a density measurement, so we turn our attention to the measurement of density.

DENSITY MEASUREMENT PRINCIPLES

It is fairly standard in the oil service industry to measure *in situ* formation density by means of gamma ray scattering. Without going into the engineering details of down-hole instrumentation, let us examine first how well gamma ray scattering or attenuation can be used to determine the density of a sample (of rock or otherwise). The simple experimental model that we retain from our school days shows, in Figure 3, a beam of gamma rays (or x-rays) of some intensity (# of gamma rays/cm^2 – sec) or flux, Φ, impinging on a thin sample (dx) of material characterized by having N nuclei/cm^3 and n scattering centers/cm^3. The experimental observation is that the flux decrease is proportional to the impinging flux, the scattering center density n, and the thickness dx. The constant of proportionality is known as the scattering cross section, σ, and thus the observation can written as

$$d \quad = -\sigma \quad n\,dx.$$

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Integrating the expression, we have the well-known exponential attenuation law

$$= \;{}_{o}\, e^{-n\sigma x}\,. \qquad (2)$$

This simply states that the flux attenuation is exponentially dependent on the path length of the gamma rays, x, and on the number density of scatters. For the medium energy gamma ray used in logging (usually Cs^{137} emitted at 662 KeV) the dominant interaction between the source energy gamma rays and the formation is through Compton scattering. This type of scattering is an interaction between the gamma rays and the electrons associated with the nuclei in the scattering material and thus n is the number of electrons/cm^3. To connect the attenuation of gamma rays to the density of the material we need simply to recast equation (2) in terms of density by connecting it to the number of nuclei/cm^3 and the number density of electrons, n, by means of Avogadro's constant, No.

The number of scattering centers per volume can be obtained for a substance of atomic weight A and density ρ_b from the following expression

$$n = N_o \frac{\rho_b}{A} Z\,,$$

where the additional factor Z gives the number of electrons per atom. With this relation in hand the attenuation expression can be rewritten as

$$= \;{}_{o}\, e^{-N_o \frac{\rho_b}{A} Z \sigma x} = \;{}_{o}\, e^{-N_o \rho_b \frac{Z}{A} \sigma x}\,. \qquad (3)$$

Since Z/A is ~½ for most materials, it is convenient to define the electron density index as

$$\rho_e \equiv 2\left(\frac{Z}{A}\right)\rho_b \approx \rho_b\,. \qquad (4)$$

Using this definition it is seen that the gamma ray scattering is just an exponential function of electron density index rather than bulk density

$$\propto e^{-\rho_e x}\,.$$

The point of this exercise is to remind ourselves that the inference of the bulk density from a measurement of gamma ray scattering is only approximately correct for any material that doesn't satisfy the relation, $Z/A = ½$. Some examples of deviant elements (for which $Z/A \neq ½$) are Al (used as a calibration block), Na, and Cl, (so the inferred density of NaCl will be problematic). The most glaring example, however, is H with a ratio of unity, which causes the electron density index of water to be 11% larger than its bulk density. This would create problems for porous media were it not for a simple transform proposed many years ago and adopted by all service companies (Gaymard and Poupon, 1968). The density inferred from gamma ray scattering (which is the electron density index, ρ_e) is modified by the following expression

$$\rho_{\log} = 1.0704\,\rho_e - 0.188\,. \qquad (5)$$

This transform of the measured value practically eliminates the problem in porous water-filled sedimentary for-

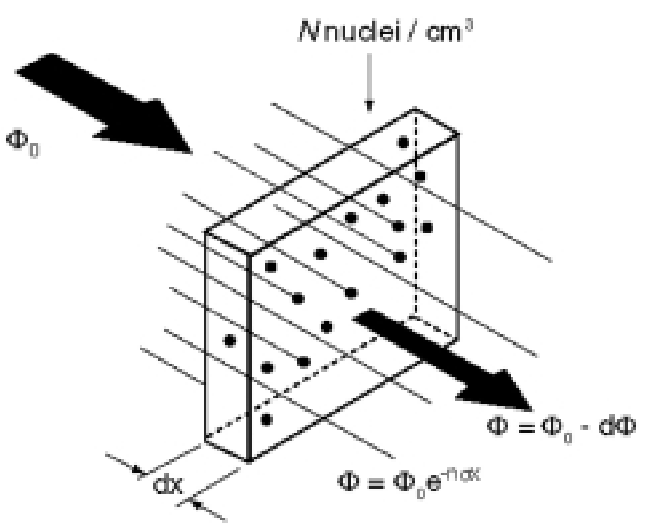

FIG. 3 The attenuation of gamma rays by a sample of material characterized by n scattering centers/cm^3 and thickness, dx.

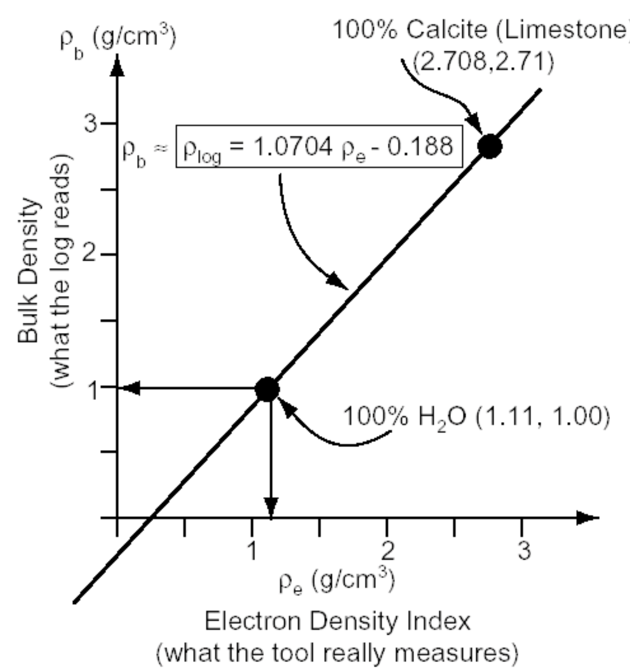

FIG. 4 The transform from electron density index to log density.

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mations. Figure 4 shows how it was derived. Plotted on the x-axis are the values that a scattering device would measure (the electron density index) for water and for a non-porous limestone. On the y-axis are plotted the bulk density values desired to appear on the log. The most notably different value is for water, which is required to appear on the log at 1.00 g/cm^3 rather than 1.11. The equation of the line connecting the two points is that given in equation (5).

Although in porous water-filled sedimentary formations the gamma ray scattering density problem has been practically eliminated by the transform noted above, one must always be alert to the possibility of seemingly spurious values of density being reported for substances that deviate far from the expected Z/A. Tables of these discrepancies can be found elsewhere (for example, Schlumberger, 1989), but one common example should be noted—Halite (or NaCl) whose bulk density is 2.165 g/cm^3 has a transformed value of 2.04 g/cm^3, an error of ~0.12 g/cm^3. This discrepancy on the occasional log has led novices and others to question the measurement. Figure 5 illustrates a number of discrepancies that can be anticipated. It is not tool-specific and should be applicable to any gamma ray scattering device or logging tool that uses a mid-range gamma ray source so that the measurement is dominated by Compton scattering. Note that air or low pressure gas-filled formations seem to dominate the graph—they lack hydrogen and thus are inappropriately shifted by the transform appropriate for water-filled formations.

GAMMA RAY SCATTERING AND LITHOLOGY

The equation (3) that describes the attenuation of gamma rays contains the cross section, σ, which until now has been treated as just the Compton cross section. In fact, it is the sum of two principal contributions, Compton scattering and photoelectric absorption. The probability of photoelectric absorption depends on the gamma ray energy and on the atomic number, Z, of the scattering material. This means that σ is not a constant but a function of the gamma ray's energy, E. Furthermore, as the energy of the gamma ray decreases (as it does as it scatters) or if the scattering media has a high atomic number, the photoelectric absorption could easily dominate the attenuation law.

The implication of a two component cross section is that for a hypothetical gamma ray transmission experiment such as shown in Figure 1, a change in transmitted flux (or in detected counting rate in a practical realization) associated with a change in sample of material (assuming that the thickness is kept constant) could be caused by either a change in sample density or change in atomic number, or both. If the object of the experiment is to measure the density then the effects of variable Z can be minimized by using a high-energy gamma ray source and detecting high-energy gamma rays, as is done in logging devices. In borehole density logging, far from the simple transmission experiment, the detected gamma rays may have scattered many times on their path from source to detector, producing gamma rays with a wide distribution of energies. The variations in Z in the formation or in absorbing mud will affect the distribution of gamma rays arriving at the detector—the highest energy gamma rays will carry density information while the lowest will be affected by density and the Z of the scattering medium.

A practical unit to describe the Z of a mineral mixture is the so-called photoelectric factor or P_e. For a single element of atomic number Z it is defined as $(Z/10)^{3.6}$. For any mixture of materials it can be computed from the sum of the P_e values of each element in the mixture where the weighting fractions are simply the mass fraction of each element. The strange exponent in the expression for P_e comes from the empirical dependence of the photoelectric absorption coefficient on the atomic number of the material, in the energy interval of 40-80 KeV. The parameter P_e is simply proportional to the photoelectric cross section/per electron.

The attenuation of gamma rays can be re written as

$$= {}_{o}e^{-N_o \rho_b (a(E)P_e + b(E))x}, \qquad (6)$$

where now the cross section, σ, has been replaced by $a(E)P_e + b(E)$ indicating that the coefficients a and b are energy dependent. However the coefficient, a, associated with P_e varies as ~1/E^3 whereas the coefficient b, associated with the Compton scattering is practically constant. Figure 6

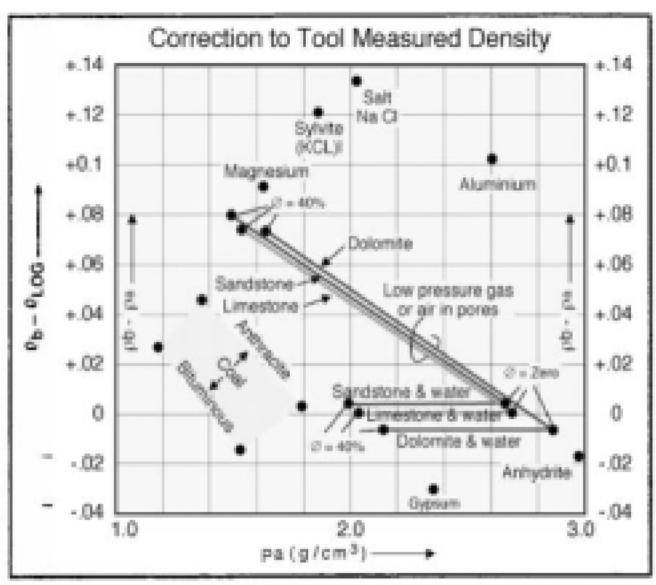

FIG. 5 Corrections necessary to transform log readings to bulk density for a few unusual cases (from Schlumberger, 1989).

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shows, on the left half of the plot, the locus of equal probability for Compton scattering or photoelectric absorption, as a function of gamma ray energy and atomic number of the scatterer. At lower gamma ray energies the photoelectric absorption dominates the process even for sedimentary rocks (which have an average Z between 11 and 16). The horizontal line at 13 corresponds to aluminum, which can be viewed as a suitable proxy for a real rock when dealing with gamma ray scattering. At very high energy (above ~1 MeV) a third process for gamma ray interaction becomes available. It is called pair production and need not be of any concern for gamma-gamma density devices employing Cs^{137} sources with gamma ray emission at 662 KeV, well below the pair production threshold.

A measurement technique that compares the propagation of gamma rays at higher and lower energies can be used to determine the amount of absorption due to the photoelectric effect, and thus to deduce the P_e of the scattering material (rock). The ability to deduce the P_e of the formation can, in the simplest of circumstances, distinguish between three of the common minerals, or lithologies, that form sedimentary rocks. This is shown in Figure 7. Use of this parameter in the example summarized in Table 2 could eliminate the nearly 4 p.u. of uncertainty associated with the matrix ambiguity.

In the simplest of circumstances, in distinguishing sand from limestone or dolomite, this would be very useful. In binary mixtures it can also be useful when combined with the density measurement or with some other logging measurement. However, often the use of such techniques is highly compromised by the presence of barite weighting agents in the drilling mud. The large Z of Ba (56) makes it a very efficient low-energy gamma ray absorber, so any amount of it in mudcake or in the invasion fluids can seriously alter the apparent P_e of the formation to the point of rendering it useless for interpretation. On the other hand there are many examples where the borehole is smooth enough or where there is no mudcake or invasion, that the P_e values can still be used in much of the logged section.

BOREHOLE DENSITY DEVICES

It is a bit of a leap from the simple gamma ray transmission experiment we have been discussing, to a device capable of making a measurement of a formation from a borehole. The schematic of such a device is shown in Figure 8. Although not indicated in the figure, the tool is pressed up against one side of the borehole by a back-up arm that also serves to measure a diameter of the borehole. This measurement is usually listed on the log as caliper or CALI, (an example of which can be found in Track 1 of Figure 1). Shown are two detectors at fixed spacings from the source. These are analogous to having two samples of two different thicknesses in the transmission experiment. Unlike the transmission experiment, the source is well-shielded from the two detectors and only scattered gamma radiation is detected. Of course, the intensity of the scattered radiation will in large measure be dominated by the density variations along the path from source to detector. The typical situation shown in the figure is that the density of the formation must be determined through an unknown amount of stand-off of material with an unknown density. Traditionally this has been addressed by including a second detector, or more recently, multiple detectors that attempt to make a compen-

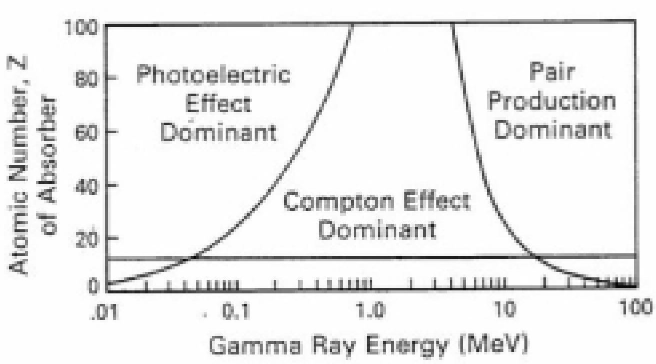

FIG. 6 The regions of influence of three types of gamma ray interactions (from Ellis, 1989).

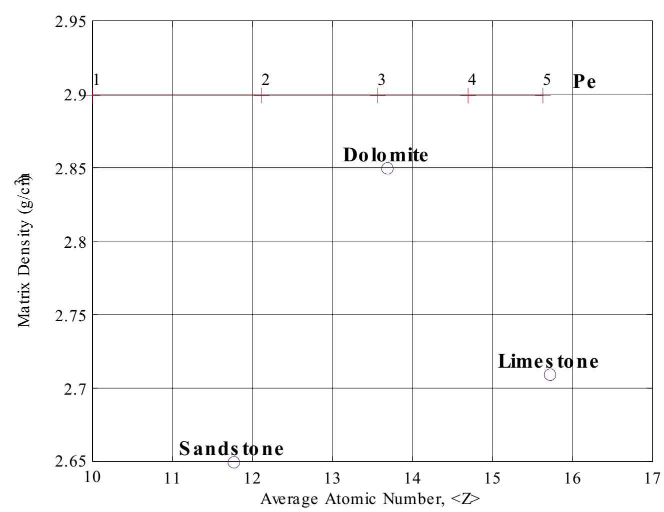

FIG. 7 Three types of sedimentary rock matrices characterized by matrix density and average atomic number. The scale of the non-linear transform to the photoelectric factor P_e is shown near the top of the figure.

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sation of the stand-off to greater or lesser degrees of success.

It is instructive to recall the operation of a generic dual-detector density device, whether it be a wireline or Logging While Drilling (LWD) device. The design of a density device exploits the attenuation of gamma rays on their path from source to detector. It is possible after calibration to convert the measured counting rate of a detector at any spacing from the source to an apparent density. If there is no stand-off (of mud or mudcake) between the tool face and the formation, and if the tool is properly calibrated, then the apparent density will be equal to the true formation density. Generally the longer spaced detector, with its larger depth of investigation is taken as the formation density estimate.

When there is stand-off between the tool face and the formation the apparent long spacing density will no longer be equal to the formation density; it requires compensation or correction. This correction is often referred to as $\Delta\rho$ and is the quantity which is added to the long spacing density (ρ_{LS}) to get the formation bulk density (ρ_b)

$$\rho_b = \rho_{LS} + \rho$$

But where does $\Delta\rho$ come from? It can be generated from

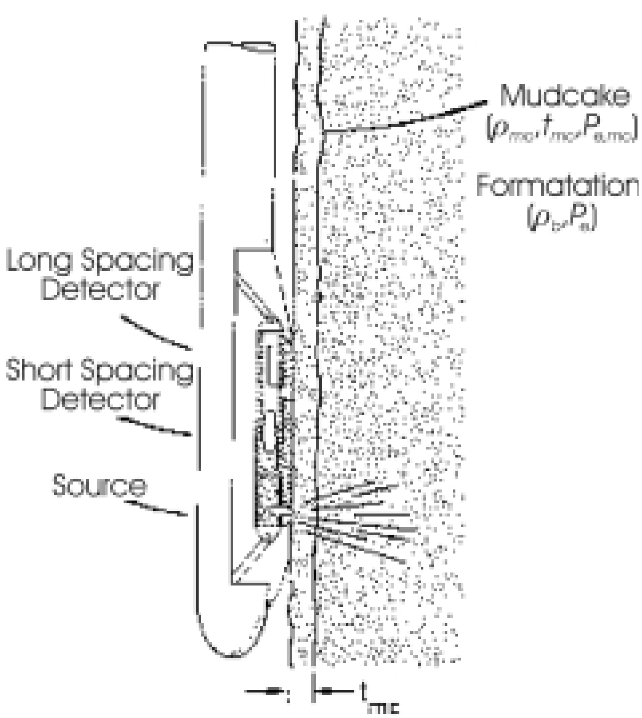

FIG. 8 A generic borehole density logging device with a source and two detectors. Not shown is the back-up arm (from Ellis, 1989).

the difference noted between the apparent density seen by the far detector and the near detector ($\rho_{LS} - \rho_{SS}$). The two density estimates will differ when there is a stand-off between the tool face and the formation, assuming that the space is filled with a material of density different from the formation density. The shallower depth of investigation of the short-spacing detector makes it much more perturbed by the presence of the interposed mudcake or stand-off. The actual correction function can be determined empirically by placing the density device in a number of formations to measure the apparent long-spaced and short-spaced densities for various thicknesses of interposed mudcakes of a variety of densities. Generally speaking, for a tool with stand-off in a low density mud both the long- and short-spacing densities will be less than the formation density, but the short-spacing density will be the lower of the two. The correction value ($\Delta\rho$) will thus be positive and its size is proportional to the stand-off gap. For this reason it is frequently used as a quality control indicator for the compensated density value.

A correction curve (labeled Delta Rho) can be seen in the left-hand track of Figure 1. In section A there is a long stretch where $\Delta\rho$ is nearly zero, indicating good contact between tool face and formation. However, above and immediately below this smooth section there are a couple of positive $\Delta\rho$ spikes, indicating some stand-off between the tool face and the formation and that the material in this gap is of lower density than the formation.

In the case of weighted muds or mudcakes whose densities exceed the formation density the opposite will be true. The short spacing density will be larger than the long spacing and their difference will be negative. A corresponding negative $\Delta\rho$ correction value will be generated to reduce the long spacing estimate to the appropriate formation value. It is helpful to remember that the correction signal, $\Delta\rho$, is related to the product of the gap between the tool and the formation, and the density contrast between the gap filling material (mudcake) and the formation. Thus a large amplitude $\Delta\rho$ might not mean a large gap but rather a small gap with a large density contrast.

Most modern two-detector density devices use multiple energy windows to derive the density, the photoelectric factor, and the correction curve as described above. In one three-detector wireline version (Eyl et al., 1994), the combination of multiple detectors and multiple energy windows produce on the order of a dozen counting rate measurements at each depth. Each counting rate can be described by a forward model relating the rate to the five important parameters of density logging (and as indicated in Figure 8): formation density, ρ_b, formation photoelectric factor, P_e, mudcake density, ρ_{mc}, mudcake photoelectric factor, P_{emc}, and the thickness of the mudcake, t_{mc}. The coefficients of the for-

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ward model are determined by placing the tool in a large number of formations with and without interposed thickness of artificial mudcakes of different compositions. Then an inversion scheme determines the five parameters by updating estimates for each of the five until the forward model predicted counting rates agree in a least-squares sense with the measured counting rates. Measurement quality estimates abound with this approach. The estimated value of t_{mc}, the goodness of the counting rate reconstruction and a computed value of $\Delta\rho$ can be used to establish confidence in the measured value.

LWD density devices

To be even-handed a few words are necessary for LWD density devices. As they are derived from their earlier cousins, the wireline devices, their similarities are overwhelming. They have a source and a long-spaced and a short-spaced detector. The only difference is that the LWD density devices are built into the drilling collars and are generally close to the bit. As part of the drilling string they also rotate. Consequently the data is generally acquired as a function of time along with orientation information so that the data can be binned with respect to hole orientation. In Figure 9 the data is collected in four geometric sectors (for imaging purposes many more bins may be used). In the figure on the left, the horizontal borehole is at the boundary of two formations with different densities, foreshadowing a difference in the measured density between the upper and lower quadrants. In the figure on the right, where the tool is run without a stabilizer, the density most representative of the formation corresponds to the bottom quadrant, and a significant correction should be apparent when the tool is pointed towards the top of the hole.

Figure 10 show one version of the multiple density traces that might be available from an LWD density measurement. In this example there is a fairly obvious discrepancy between the upper and bottom quadrant density estimates. This discrepancy can be caused by the well bore lying at the intersection of beds of two different densities as indicated in the left-hand sketch in Figure 9. Due to the action of gravity, in a highly deviated well, the bottom quadrant is frequently the curve with the least perturbation. Inspection of the correction curves in the log of Figure 10 confirms that the $\Delta\rho$ curve in the bottom quadrant is the least active of the four presented and is the one that is closest to zero over most of the section displayed. In an over-sized or washed out hole, the measurements around the circumference may contain significant error if the compensation range is exceeded. Another benefit of the rotational measurement, in appropriate sized boreholes, is the possibility of deriving density- or P_e-based images as an alternative method of sensing and quantifying dipping beds.

One of the advantages of the LWD density, with its proximity to the drilling bit, is the relatively short time between drilling and measurement. From this fact come two advantages. The first is the condition of the borehole wall, that usually deteriorates with time. Thus rugosity is at a mini-

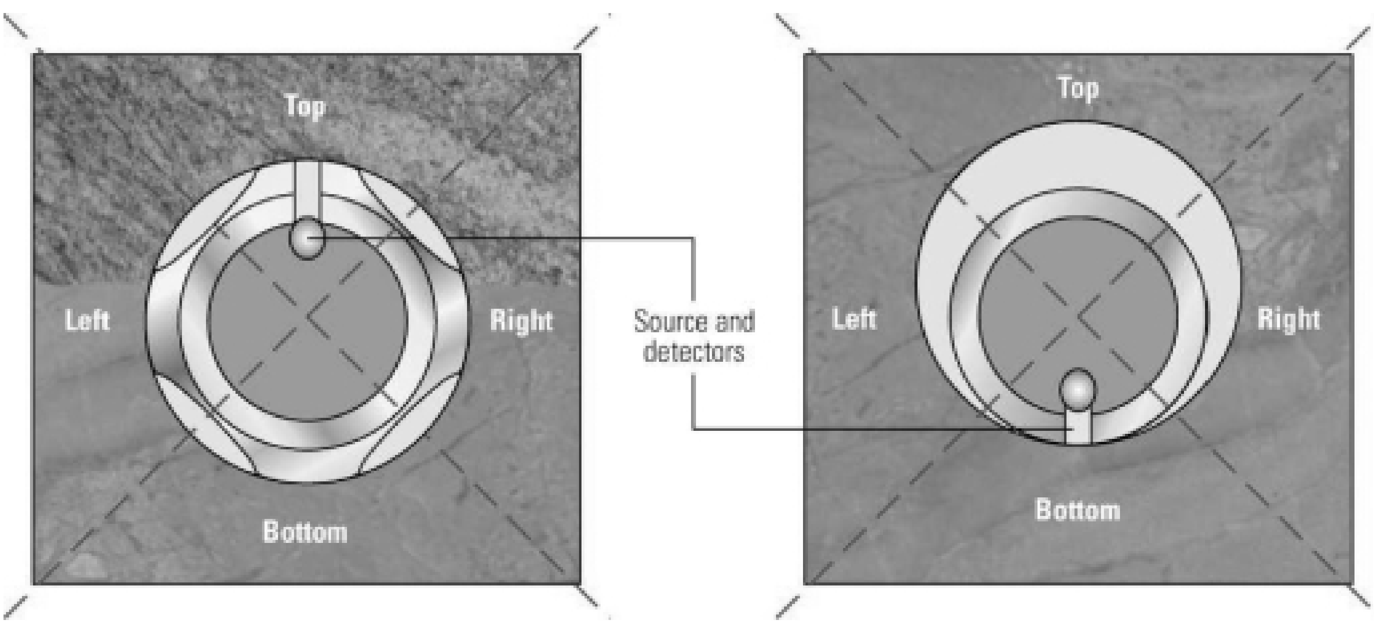

FIG. 9 An example of an LWD density tool is seen built into one side of the drill collar. As the pipe rotates the density is collected continuously and binned, in this example into four quadrants (from Bourgois et al., 1998).

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mum. The second is the short time available for invasion to proceed. This means that the value of ρ_f must not be assumed to be mud filtrate but rather the virgin formation fluid. Hansen and Shray (1996) have documented the consequences of using an incorrect fluid density for interpreting an LWD density log in an oil reservoir containing light hydrocarbons.

ENVIRONMENTAL EFFECTS OR WHERE DOES THE SIGNAL COME FROM?

What is needed to obtain a reasonable estimate of porosity is a good sense of when a density measurement can be trusted and when it can't. The most important shortcoming of the density measurement is related to the relatively short range of penetration of the gamma rays. A parameter for helping to quantify this is the so-called mean free path. It is defined as the distance over which 1/*e* of the gamma rays will have been scattered. For the medium-range gamma rays used in well logging, the approximate mean free path is between 4 – 6 cm for the density range of 2 to 3 g/cm^3. Of course, the spacing between the gamma ray detector and the source, usually several multiples of the mean free path, will also have an influence on depth of investigation. Because of the relatively short mean free path and the spacings of the compensating detector(s) there is some practical range of parallel stand-off (caused for instance by a layer of mudcake) for which the compensation can be made. This distance is likely to be on the order of 1-2" for most logging tools but can vary with equipment design.

To illustrate the depth of investigation of a hypothetical density logging tool refer to Figure 11. It shows the density response map for a long-spaced and below, for a short-spaced detector. The positions of the source and detector are indicated by the symbols "S" and "D" in the figure. These maps are analogous to the geometric factor maps of the various arrays of an induction tool. Note the exaggeration of the radial scales. The radially integrated depths of investigation are projected onto the back plane of both figures. The 90% response point for the shorter spacing detector is on the order of 1.5" whereas that same point for the farther spaced detector is somewhat greater than 4".

It's important to note a difference between the behavior of gamma rays and neutrons. Gamma rays can be collimated with reasonable amounts of not so exotic materials. Neutrons, on the other hand, are nearly impossible to collimate in the borehole environment. The important parameter is the mean-free-path. This number, for gamma rays, is inversely proportional to the density of the material. Thus a dense substance such as iron, or better yet, lead or depleted uranium makes a good attenuator or shield for gamma rays. This is mentioned because a borehole gamma-gamma den-

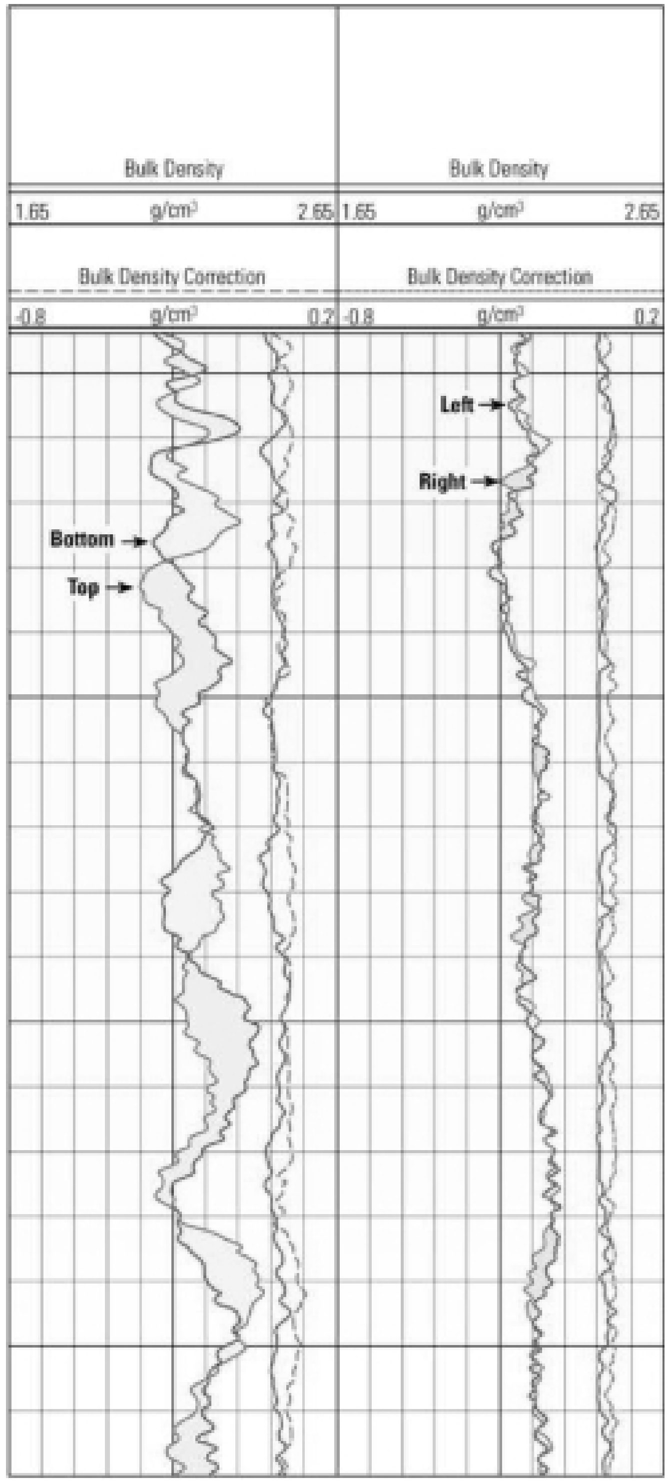

FIG. 10 An example of a LWD density log where the data has been collected in oriented quadrants (from Bourgois et al, 1998).

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sity device is highly collimated. Source gamma rays are collimated to favor their entrance into the formation at the face of the device in contact with the formation, and the detectors are back-shielded to make them nearly immune to gamma rays coming from the borehole and to detect only those gammas that arrive from the formation. Consequently a gamma-gamma device is nearly insensitive to the borehole environment.

The list of environmental effects of the density tool, then, is quite short. There is some hole size effect because the radius of curvature of the pad of the measuring device cannot conform to all borehole sizes. A region of mud, with a crescent-shaped cross section, may be present along the sides of the skid. If the density contrast between the mud in this crescent and the formation is large it is possible that

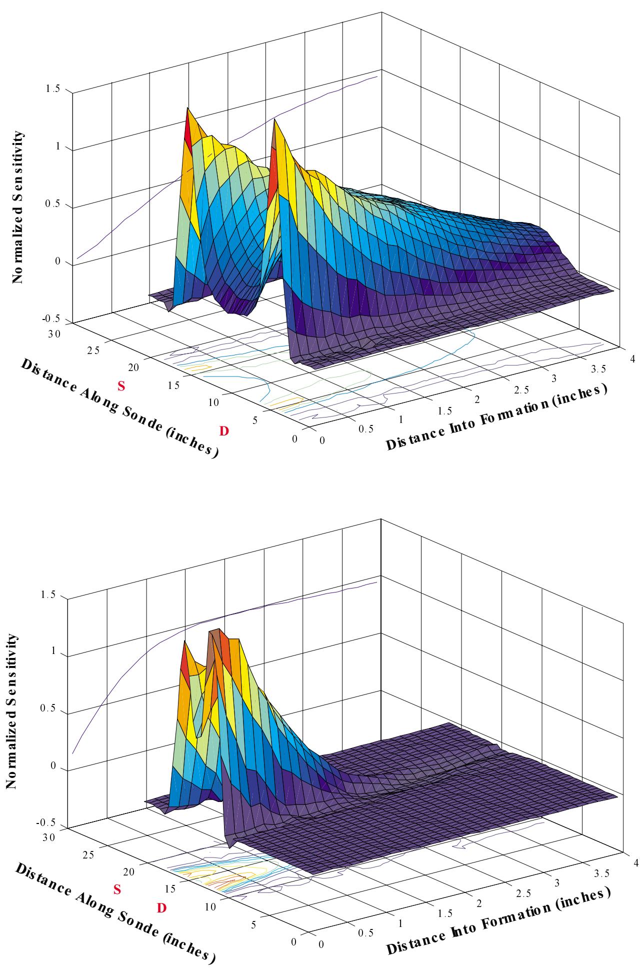

FIG. 10 Density response maps for a hypothetical two-detector density device. The top figure corresponds to a far-spaced detector and the bottom figure to a short-spaced detector.

some correction needs to be made. Charts are provided for such corrections, but generally they are of very small magnitude.

However, the number one problem for obtaining a good density estimate comes from the rugosity of the borehole wall. Although the compensation schemes described earlier are relatively successful, they are strictly applicable only for parallel stand-off. In the case of rugosity (which we will define as some irregularity in the borehole wall with a length scale less than the source-detector spacings and with an amplitude in excess of a few mm), the effect on the measurement can be deleterious. In Figure 1, Zone B shows a region of obvious rugosity; the borehole irregularity is seen on the caliper curve and also manifests itself in a high degree of correlation between the $\Delta\rho$ curve and the caliper. The anti-correlation between the density curve (or DPHI here) also suggests an incomplete compensation of a highly perturbed long-spaced detector. Thus, the density curve is probably not representative of the formation in this zone.

Of course it is imagined that because the measurements are not made just at a point, but by moving along the formation and averaging the counting rates (and thus the density), any rugosity will just average out to some equivalent standoff. This may often be the case. However, there are certainly times when this is not the case. The example of Zone B, above, is one of those cases. It is quite evident from the response maps in Figure 11, that most of the signal comes from the formation closest to the tool face; an unavoidable consequence of the small mean-free-path of the gamma rays. Since rugosity simply represents patches of low density formation, the response peaks in front of the source and detectors will exaggerate the influence of the rugosity on the counting rate.

The auxiliary measurement that is most helpful to indicate suspicious density readings is the caliper (for LWD, use the next best, $\Delta\rho$). If there is a high degree of correlation between the compensated density and the caliper on length scales shorter than source-detector spacings, then one should be wary. Generally speaking, if the amplitude of small-scale irregularities can be seen on a normal caliper logging scale, then it will have a density that is most probably perturbed by the borehole roughness.

A SUMMARY OF SORTS

After pages of rambling, what practical information should be retained? First, remember how the density measurement is made. It is from gamma ray scattering. Beside the issue of electron density versus bulk density, don't forget that the measurement is best made when the logging device is in good contact with the formation. Good contact

Continued on page 22…

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implies a smooth borehole surface or the absence of rugosity or "wash-outs."

So the first thing to do before making an interpretation of the density log, is to look at the caliper (if available) in the desired zone. Is it smooth? Is the correction curve also smooth? For an oriented LWD measurement the bottom quadrant might be the best choice—the character and amplitude of the $\Delta\rho$ curve will indicate which to use. Then use the density curve with the appropriate values of matrix density and fluid density to estimate the formation porosity. The P_e curve, if unaffected by barite in the mud, may be useful for confirming or deriving a matrix density.

If the caliper is visibly erratic and the correction curve correlates with it, then beware of putting too much confidence in the density measurement.

ACKNOWLEDGEMENTS

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Darwin V. Ellis is a Scientific Advisor at Schlumberger-Doll Research in Ridgefield CT. He began his career with Schlumberger after obtaining a Ph.D. degree in Physics and Space Science from Rice University. He has worked in many capacities in Schlumberger locations in Houston, Paris, and Ridgefield in over three decades of well logging research and engineering.

In addition to engineering a density logging tool, he has worked on Monte Carlo modeling, geochemical logging, neutron and density log interpretation, signal processing applied to nuclear logs, environmental logging, and logging-while-drilling (LWD) interpretation. More than a decade ago, as a Consulting Professor, he taught well logging classes at Stanford University for two consecutive winter quarters. The fruit of this labor was his well known, but difficult to find, textbook Well Logging for Earth Scientists, published by Elsevier in 1987.

Besides formation evaluation, Darwin has always had a very strong interest in applying logging technology to subsurface investigation in general.. In 1996, he was a recipient of the SPWLA Distinguished Technical Achievement Award. He is the author of over one hundred internal and external reports and has been granted 7 patents.

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Canadian Well Logging Society

Wednesday, June 9th, 2004

CWLS Technical Luncheon Presentation
Fairmont Palliser Hotel 133 – 9th Avenue S.W., Calgary

Time: **12:00 pm (Cocktails at 11:30 am)**

Reservations By: **Friday, June 4th, (noon) - Call 269-9366 to Confirm a Seat**

Cost: **Members reserved meal (with confirmed seat): $25.00; Members at the door: $30.00**
Non-Members reserved meal: $30.00; Non-Members at the door: $30.00
(Special needs meals available with advanced booking only)

Topic: **Formation Damage Issues Impacting the Productivity of Tight Gas Producing Formations**

Speaker: **Brant Bennion, Hycal Energy Research Laboratories**

Abstract:

Very low in-situ permeability gas reservoirs (Kgas <0.1 mD) are very common and represent a major portion of the current exploitation market for unconventional gas production. Many of these reservoirs exist regionally in Canada and the United States and also on a worldwide basis. These reservoirs have many unique challenges associated with the drilling and completion practices required in order to obtain economic production rates. Formation damage mechanisms affecting these very low permeability gas reservoirs, with a particular emphasis on relative permeability and capillary pressure effects (phase trapping) will be discussed in this presentation. Examples of reservoirs prone to these types of problems will be reviewed, and techniques that can be used to minimize the impact of formation damage on the productivity of tight gas reservoirs will be presented.

Biography:

Brant Bennion received B.Sc. and Ph.D. degrees in Chemical Engineering from the University of Calgary and has been involved in researching formation damage mechanisms in oil and gas reservoirs for over 25 years. Brant has authored over 200 technical papers on the subject and has lectured extensively in over 40 countries. Brant has served as a distinguished lecturer for both the SPE and the Petroluem Society and is the receipient of numerous industry awards for technical services to the oil and gas sector. Brant is a registered professional engineer with APEGGA, and has been employed at Hycal Energy Research Laboratories for over 25 years. He currently serves as Hycal's president, a position he has held since 1991.

Notes: Please forward this notice to any potentially interested co-workers. Thank you.

Please see the CWLS Website at www.cwls.org for information regarding a Corporate Network License for the recently published CWLS Formation Water (RW) Catalog CD.

Canadian Well Logging Society

Wednesday, September 8th, 2004

CWLS Technical Luncheon Presentation

Fairmont Palliser Hotel 133 – 9th Avenue S.W., Calgary

Time: 12:00 pm (Cocktails at 11:30 am)

Reservations By: Friday, September 3rd, (noon) - Call 269-9366 to Confirm a Seat

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Topic: Predicting Hydraulic Flow Units for Enhanced Permeability Modelling Berkine Basin, Algeria

Speaker: Kevin Corrigan, Anadarko Algeria Company LLC
Chris Howells, Anadarko Algeria Company LLC

Abstract:

The Berkine Basin represents one of the significant success stories of Algeria with the discovery of several billion barrels of hydrocarbons. One key factor in the success of the Sonatrach-Anadarko Association was the initial value of the conventional core data. To date, in excess of 8km of core have been acquired from many different fields over a geological area extending several hundred kilometres and which, in many cases, is continuous across the reservoir interval. This extensive data acquisition and analysis program has resulted in a significant increase in geological understanding of the reservoir interval and work is currently directed towards identifying geological controls on subsurface flow of hydrocarbons and the need to better describe the permeability distribution within the reservoir. The presentation focuses on a study of a Berkine Basin field, the results of which have subsequently been applied to nearby satellite fields. The ultimate objective of the study is to better describe the 3D subsurface flow in the Triassic sandstone (TAGI) reservoirs in the Berkine Basin by improving the calculation of permeability. To this end the applicability of using Hydraulic Flow Units, as predicted by the use of an artificial neural network, is tested. The approach utilizes a program called Spotfire to identify the controlling factors on permeability and to maximize the benefit of this extensive dataset. It can be shown that a single porosity-dependent permeability predictor is insufficient to describe permeability in every well, even after extensive subdivision of the TAGI sandstone layers. It has been recognized that application of a Timur-type equation leads to a significant improvement but only in zones of irreducible water saturation above each OWC. The prediction of Hydraulic Flow Units, using the method of Abaszadeh, Fujii and Fujimoto, reduces the uncertainty in the calculated permeability, once sufficient training of the artificial neural network has taken place, and gives confidence to permeability estimation where core is not present. The authors would like to thank Anadarko Algeria Company LLC and its partners Eni-Agip, Maersk Olie Algeriet AS and Sonatrach for permission to give this presentation.

Biography:

Kevin Corrigan joined Anadarko Algeria Company LLC in 1996 where he is currently a Senior Petrophysical Advisor working in the North Africa and North Atlantic region. He has over 28 years of experience in the industry, is a Chartered Engineer and holds a BSc. degree in Physics from the University of Leicester. He started work in Schlumberger in their Log Interpretation Centre in Paris, and then as a Field Engineer in Libya and the Middle East. This was followed by 5 years in BP in their International Exploration Group in London as a petrophysicist and later in Aberdeen as a Senior Petroleum Engineer. Prior to joining Anadarko, Kevin was a consultant for 11 years working on a number of integrated, international projects out of the UK.

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CWLS GENERAL INFORMATION

INCORPORATED – January 21, 1957

Objective

The objective of The Society (as stated in the Letter of Incorporation) is the furtherance of the science of well log interpretation, by:

(A) Providing regular meetings with discussion of subjects relating thereto; and

(B) Encouraging research and study with respect thereto.

MEMBERSHIP

Active membership is open to those within the oil and gas industries whose work is primarily well log interpretation or those who have a genuine interest in formation evaluation and wish to increase their knowledge of logging methods.

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The CWLS fiscal year commences February 1, and all fees are due at this time.

Initiation Fee (including first year's membership fees) : $40.00
Annual Dues : $30.00
Student (no initiation fee) : $10.00

Memberships not renewed on or before June 30 of each year will be dropped from the roster and reinstatement of such a membership will only be made by re-application, which will require re-payment of the initiation fee plus the annual dues. All dues (Canadian Funds) should be submitted with the application or renewal of membership (Cheque, money order or Visa).

ACTIVITIES

The Society also furthers its objectives by sponsoring symposiums and exhibits.

Research committees encourage and support research on relevant problems.

The Society is the spokesman to industry and government on topics pertaining to well logging and formation evaluation.

The Society holds a monthly luncheon meeting (except July / August) to hear an address on a relevant topic.

Each active member will automatically receive the CWLS Journal, 'InSite' newsletter and Annual Report.

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Should our activities interest you we invite you to complete the attached application form and forward it to the CWLS membership Chair.

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June 9th, 2004

CWLS TECHINICAL LUNCHEON PRESENTATION

Fairmont Palliser Hotel, Calgary, AB

Brant Bennion, Hycal Energy Research Laboratories

Formation Damage Issues Impacting the Productivity of Tight Gas Producing Formations

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Predicting Hydraulic Flow Units for Enhanced Permeability Modelling Berkine Basin, Algeria

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An Arctic drilling rig on a beautiful day in the Lodgepole area of Alberta.

Photo Courtesy Bruce Greenwood

The resistivity meter used to make Rmf, Rm and Rmc measurements in a logging truck. Note the cup of amber colored filtrate.

Photo Courtesy Robert Bercha

Dean Stark apparatus used to determine the water content of a core sample.

Photo Courtesy Robert Bercha

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