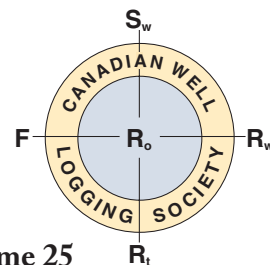


InSite

CWLS Magazine

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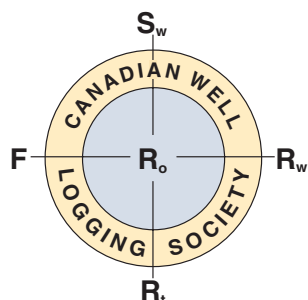
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Cover Photos: *Flying at 10,000m over a sea of sand dunes in Oman on the way into Riyan, Yemen. Photo courtesy of Ben Urlwin*

Equipment and tanks rigged up on location in preparation for a 240t frac completion. Photo courtesy of Ben Urlwin.

If you have a photo that the CWLS can use on its next InSite cover please send a high resolution jpeg format version to tmaksymchuk@br-inc.ca or ben@waveformenergy.com. Include a short description of the photo with your submission.



The 2006 - 2007 CWLS Executive:

Front row (l - r): Jeff Taylor, John Nieto, Peter Kubica, Michael Stadnyk

Back row (l - r): Gordon Uswak, Gary Drebit, Dave Ypma, Benjamin Urlwin, Tyler Maksymchuk



President's Message

Welcome back to CWLS activities, starting with the lunch meeting in September. Our executive has been active on a number of issues that I would like to share with the society membership.

CWLS has participated in sending a letter to AEUB proposing to replace mandatory submission of paper copies of wireline surveys with image files. We believe that this would result in substantial savings to the industry. We hope that AEUB will seriously consider this recommendation from the industry to bring about much needed changes in data submission regulations.

Financial results of the past joint symposium of CSPG-CSEG-CWLS will be soon announced. Initial estimates indicate a significant contribution to our treasury.

At this time I would like to thank the CWLS members participating in organizing committees of the symposium for their contribution that made the symposium a technical, as well as a financial, success. The following CWLS members participated in preparation of the symposium:

Roy Benteau – Symposium Co-Chair

Darren Aldridge – Symposium Finance Chair

Mike Seifert – Symposium Sponsorship Chair

Alan Pickel – Technical program Chair for CWLS

Brian Glover – CWLS Courses Chair

Bernie Cossette – Poster Session Co-Chair

The joint SPWLA-CWLS topical conference on stress analysis and stress interpretation (Petrophysics Under Stress) is scheduled for Oct 30-Nov 2/2006 at the Kananaskis Lodge. Speaker selection and program have now been completed. You can register for this event through SPWLA website. More detailed information about this conference is also available on our CWLS website. Three members of CWLS are on the organizing committee and they contributed by securing speakers from Western Canada. I hope that some of you will take advantage of the proximity of this conference.

Our Special Core Analysis database is also being enhanced due to the continuous efforts of Taras Dziuba. The CWLS executive approved funding to expand the database to include CBM sample data.

We have also approved funding to further enhance our CWLS website: soon you will be able to purchase your monthly lunch tickets on-line. We expect this to become a popular way of registration by improving the efficiency of this process.

Our Awards committee together with the executive made a selection of the 2006 CWLS student award winner. This award will be presented at our September lunch meeting. In the near future we plan to improve our exposure to students at Canadian universities to increase student awareness of careers in Petrophysics and Formation Evaluation.

Finally, John Nieto and myself recently participated in meetings of the Canadian Geoscience Council (CGC). This is an umbrella organization of many geoscience societies in Canada. A renewal of CGC is underway with the election of a new President from the oil industry. Among other benefits, our participation in CGC may result in better exposure of our professions at the universities, financial support in research activities, as well as having influence on geosciences educational programs at high schools.

I hope to see many of you at our September lunch.

Do not hesitate to contact me with your concerns or suggestions for CWLS.

Peter Kubica

CWLS President

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Editor's Note

Welcome everyone to this edition of the CWLS InSite. Hope everyone had a well deserved summer break? As you are aware, all members of the CWLS executive will be back at it at the next CWLS executive meeting where we will be preparing diligently for the next agenda and making plans for the upcoming luncheons and yearly annual general meeting, as well as discussing the various topics of this month's agenda. If you have comments or questions, please feel free to contact any one of your CWLS executive and we will add your items to our agenda.

I am happy to say that in this InSite we have once again two new papers ready for press, as well as some very interesting additions in the form of continued papers and feedback concerning past issues. Our first paper is the second half of Gene Bailey and Roy Cox's submission on the intricacies of formation evaluations in carbonate versus sandstone reservoirs. Our second paper discusses the advancements made in the area of sensing vertical migration of volatile compounds from oil and gas reservoirs, and is presented to us by Bob Potter and Harry Anderson. Both Bob and Harry have extensive backgrounds in this area and bring some interesting points to light on surface geochemical measurement, and its uses as an exploration tool. Our Tech Corner this month comes from Kenneth Heslop, who discuss the issues, and advancements, in permeability measurements from open hole logs which is an illusive beast to be sure.

We are also privileged to have a response to the last of the four Myth Interpretations supplied to us by Ross Crain. This response comes to us from Italy where Mr. Mauro Gonfalini, brings to light even further issues surrounding anomalous density readings in exotic terrains, and also shows us that Italy definitely has some interesting mineralogy.

We would like to thank all of our contributors for their continued supply of material for us to publish: without you, there would be no InSite.

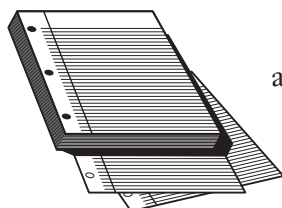
Next, I would like to take some time to remind our readers that we have a joint SPWLA and CWLS conference coming up towards the end of October and into November. This is a topical conference to be held out in Kananaskis on Geomechanics. Lastly I would now like to congratulate two attendees from the June luncheon, Andrea Pintaric and Eric Stobbert who won prizes donated by Nexen and Tucker respectively. Thanks once again for all the attendance and Good Luck to all our attendees at the next luncheon here in September.

Please note that we will always be in need of technical papers for future editions of the InSite and any information that you believe is appropriate and relevant to the daily work of our membership, will be submitted, reviewed and likely published. Thanks very much for your attention to the CWLS InSite publication and if you have any comments, concerns or questions please contact either Tyler or Ben at the email addresses below.

Enjoy this edition of the InSite!

*Tyler Maksymchuk
Ben Urlwin
Co-Chairs of Publications*

Call for Papers



The CWLS is always seeking materials for publication. We are seeking both full papers and short articles for the InSite Newsletter. Please share your knowledge and observations with the rest of the membership/petrophysical community. Contact publications co-chairs Ben Urlwin (ben@waveformenergy.com) at (403) 538-2185 or Tyler Maksymchuk (tmaksymchuk@br-inc.ca) at (403) 260-6248.



As the Winch Turns: Too Long in the Bush

I hate flying. I mean I really hate flying. Anyone that knows me knows that I hate flying. This is odd, because I spent parts of 6 years working in Sudan and another two in Egypt. Both places entailed long hours on various aircraft whose natural place of rest is on the ground, sometimes in pieces. Once, when the rebels attacked our rig I stopped before getting on a helicopter to seriously consider whether it was less stressful to fly or to remain and get shot at. I have only ever once heard of someone who hated flying more than me and that was person was a cow.

We were working in central Sudan for State Petroleum drilling rather successful oil wells. The political situation had grown worse as time went on and we were increasingly successful. When we first went there we could wander anywhere at anytime in complete safety. We were probably safer there than in downtown Calgary, if only because there were very few vehicles on the road. But as the project progressed and the number of people in the field increased there were threats made. Most of these came from the Sudanese People Liberation Army. The SPLS used to send nasty faxes occasionally and rarely have some friends come and shoot at the rigs to liven things up and help us avoid boredom.

The oil company brought in some ex-police types to provide security but mostly they were just extra mouths to feed. The only thing they did that directly affected us was to tell us that we could not stop and help people. This really bothered me because I have always been proud of

Canadians and the way they will for the most part help other people -rules or no rules.

For example:

Robert the truck driver was going down towards the Unity field in his picker truck when he saw a small boy crying on the side of the road. Breaking all the rules he stopped to see what was up. After all who would know? What he found was that one of the boy's cows had got stuck in the mud at a water hole and could not exact itself. It only took a few minutes to set the outriggers and extend the picker. A few more minutes were spent fastening a rope to the cows' horns. As he brought the cow up and swung it onto the road he became aware of a whole convoy of trucks waiting on the road. It included every boss and manager imaginable, all looking really hard off into the distance. But it only got worse. When they untied the cow it was not at all grateful. In fact it was so upset about flying that it chased them around the truck. Robert said if he could have only stopped laughing he could have got away. Fortunately after a few revolutions the cow got tired and headed home with the boy happily trailing along behind. He put everything away and left. Meanwhile everyone in the still stopped convey were still staring hard at the far horizon.

But I still think the cow had the advantage on me. As far as I know this was its only time it flew.

Dave

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Message from the Vice-President

Look What They've Done To My Log, Ma. The life of a Petrophysicist

Honestly, I try to be a nice guy. I prefer to err on the side of optimism and I generally look at the bright side of things. But it seems that no matter how hard you try to be a good person, there comes a time when the entire universe rises up to smite thee. Darkness descends, the hairs on the back of your neck stand, an owl swoops overhead screeching. From the lowest, nastiest depths of this world, and all worlds, it becomes clear that something dreadful is imminent; You're going to have to evaluate that 1972 well that was digitized off the 1/1000 print made by a bambino gasping its last ammonious breath.

I can see the fresh faced geologist eagerly awaiting the marvels of Petrophysics rise like a phoenix out of the dusty pile of well files. "I'm building a model" he says excitedly.

Your left eye starts to twitch involuntarily and the beginnings of a dull ache starts somewhere between your temples. If you don't act swiftly, that monkey is about to leap off the geologist's back and find a comfy new home on yours. Desperately glancing around for an excuse, a consultant, a summer student, a black hole to another dimension, you know that you must accept your fate and the enormity of the task ahead.

The task you know all too well. It is not one spoken of too loudly and it has been avoided too long. Hence the geologist's request is all too familiar. Your task is to become much more closely involved with the asset teams, to educate them and be educated by them. To understand how the data is being used by the asset team and to make yourself understood on how the data can be used. Your new accepted role has just expanded to include regular training sessions and MBWA (management by walking around). Your task, your mission, your goal, is to be part of the team. You must no longer be seen as an external resource. You must be ready to broaden your skill base as that is what you will be asking of the asset teams. Marcel and Conrad would be proud.

I know that many of you who read this magazine are Log Analysts and Petrophysicists, and if you are, calm down. Our profession is indeed more relevant today than yesterday and that is because the value of petrophysics is being successfully communicated throughout our organizations. And why is that - nobody wants to sit in the wings.

Jeff Taylor
CWLS Vice-President
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Canadian Well Logging Society

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Kunle Babalola, Baker Atlas

Apostolos Kantzas, Perm Inc./TIPM Laboratory

Formation Evaluation: Carbonate versus Sandstone Part 2 of 2

R. E. (Gene) Ballay and R. (Roy) E. Cox, Consultants

Abstract

The professional geoscientist of today will typically work both sandstone and carbonate provinces, possibly even simultaneously. Many of the wireline tools upon which their efforts and results are based, will be the same in both environments, but the utility and underlying physical meaning of the response, may differ between sandstone and carbonate.

By summarizing the key issues, and how the routine open-hole tools respond and are used, one is able to focus their efforts in a more efficient manner. There are, of course, exceptions to virtually every rule, which is why experience in a specific field is of such value.

Long experience, with many wells successfully drilled, does not of itself eliminate surprises: Ballay (2001, 2002). In this example, with 120 successful wells (45 of which were cored) drilled, a completely unexpected poor formation was encountered in an area previously drilled. And so one returns to the value of understanding the basics, and being just as alert with well # 121, as when the first well was drilled.

This article summarizes key response attributes and sandstone vs carbonate differences for routine open-hole tools. In a later article we plan to examine specialty tools.

Editors note: part 1 of this paper was printed in the June 2006 InSite.

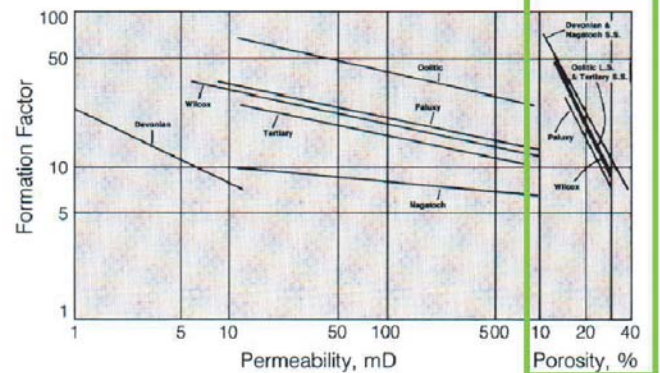
Water Saturation and the Archie Equation

In light of the differences in sandstone and carbonate, per the above discussion, it is perhaps surprising that water saturation can (often) be successfully estimated with the same equation and (similar) parameters (Figure 6).

From this (Figure 6), and similar, measurements Archie (1947) observed that the correlation between Formation Factor (ratio of water saturated rock resistivity to saturating fluid resistivity) and permeability was weaker than that of FF and porosity, which suggested to him that air permeability and ionic (resistivity) flow were 'different'.

Archie's equation, and the impact of variations in the associated parameters, can be visualized with a Pickett Plot (Roberto Aguilera 2002, 2004 and Ross Crain on-line at <http://www.spec2000.net/> and John Doveton on-line at <http://www.kgs.ku.edu/Gemini/>)

Carbonate versus Sandstone
Figure 6



Archie's 1947 Data - Sandstone and Limestone

G E Archie: Electrical Resistivity as an Aid in Core Analysis Interpretation, AAPG Bulletin 31 (1947): 350-366
Schlumberger Technical Review, Volume 36 Number 3

Carbonate versus Sandstone
Figure 7

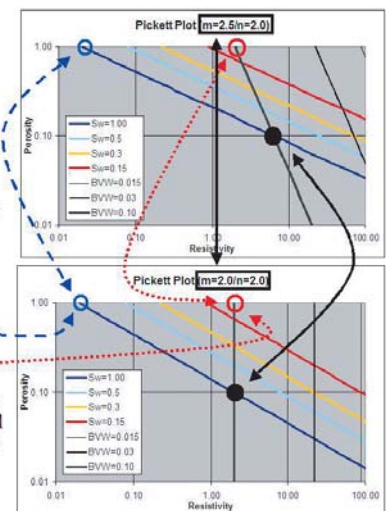
Pickett Plot with BVW Grids

• $m=2.0 / n=2.0$ vs $m=2.5 / n=2.0$

• 'm' relates to pore system tortuosity, and as 'm' increases, the resistivity of a specific porosity (10 pu in the graphic) at $S_w = 100\%$ also increases

• R_w @ FT remains the same

• Grids of constant BVW shift
• BVW lines below $S_w = 100\%$ are a mathematical extrapolation (for visual reference) and not physically realistic



Considering, for the moment, 'clean' sand and 'intercrystalline / interparticle carbonates', the cementation exponent reflects the tortuosity of the ionic electrical flow through brine saturated rock. An 'm' of 2.0 is commonly used: smaller values correspond to a less tortuous path, with fractures being a somewhat extreme example. Should the path be 'extra' tortuous, such as when the pore throats are well-cemented, or a portion of the porosity is poorly connected vugs, 'm' will increase.

Be aware, however, that small pores, by themselves, don't necessarily mean high 'm': it is the 'effectiveness' of the conduction path.

Continued on page 10...

Formation Evaluation: Carbonate versus Sandstone ... continued from page 9

The cementation exponent of both clean sand and IC/IP carbonates may vary within a relatively short (vertical) distance, and can assume a multitude of values within a given reservoir. This potential must be recognized, in order to avoid consolidating data that is in fact 'different'. These differences may, or may not, correspond to the original depositional environment.

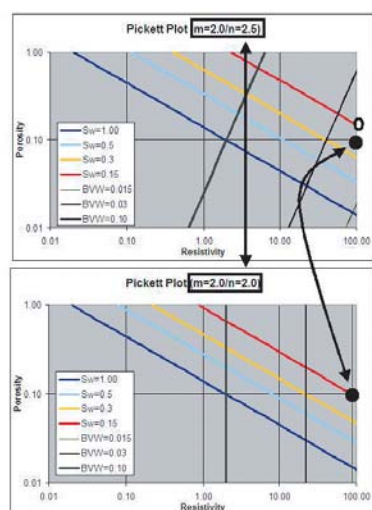
In the words of Jerry Lucia (2004): the foundation of the Lucia petrophysical classification is the concept that pore-size distribution controls permeability and saturation and that pore-size distribution is related to rock fabric. The focus of this classification is on petrophysical properties and not genesis. To determine the relationships between rock fabric and petrophysical parameters, one must define and classify pore space as it exists today in terms of petrophysical properties.

By superimposing additional grids on the Pickett Plot, such as lines of constant Bulk Volume Water, the technique takes on additional meaning. One must remember, however that these grids are also dependent upon the underlying Archie exponents, and will themselves shift just as the Archie grids do.

The saturation exponent, 'n', reflects the tortuosity of ionic electrical flow through the conductive phase, in the presence of a non-conductive (hydrocarbon) phase.

Carbonate versus Sandstone
Figure 8

Pickett Plot with BVW Grids
• $m=2.0 / n=2.0$ vs $m=2.0 / n=2.5$
• 'n' relates to the tortuosity of the conductive phase and as S_w decreases the associated rise in resistivity of a specific porosity is greater than what would have occurred at a lower 'n' value.
• Alternatively, the S_w associated with a specific porosity & resistivity increases as 'n' increases



Physically, differences in saturation exponents can reflect wettability, grain surface roughness (Diederix 1982) and possibly other variations. Again, one must heed Jerry Lucia's comments about 'describing the pore system as it exists today, versus the depositional environment'. We have been faced with laboratory data acquired from a single depositional environment in a sin-

gle well, measured in the same lab in the same way at the same time, for which the 'n' varied from 1.5 to 3.0.

Sandstone evaluation often involves clay and the correction for its contribution to formation conductivity (quartz being non-conductive). The clay distribution mode (dispersed, laminated, structural) determines how the clay and brine conductivities interact and what formulation is appropriate for improving saturation estimates.

Laminar shale forms during deposition and is interspersed in otherwise clean sands. Many logging tools lack the vertical resolution to resolve resistivity (and possibly even porosity) values for individual thin beds of sand and shale.

Intervals with dispersed clays are formed during the deposition of individual clay particles or masses of clay. Dispersed clays can also result from post depositional processes, such as burrowing and diagenesis. The size difference between dispersed clay grains and framework grains allows the dispersed clay grains to line or fill the pore throats between framework grains. When clay coats the sand grains, the irreducible water saturation of the formation increases, dramatically lowering resistivity values. If such zones are completed, however, water-free hydrocarbons may be produced.

Structural clays occur when framework grains and fragments of shale or clay, with a grain size equal to or larger than the framework grains are deposited simultaneously. Alternatively, in the case of selective replacement, diagenesis can transform framework grains, like feldspar, into clay. Unlike dispersed clays, structural clays act as framework grains without the dramatic altering of reservoir properties. None (very little) of the pore space is occupied by clay.

Dispersed clay is the most common distribution that we have been faced with (though laminated is certainly a problem in some provinces), and can be addressed with the Dual Water Model, Waxman-Smits, or several other more empirical algorithms (Worthington has authored several nice reviews). The presence of the clay offers an 'alternative' electrical path and thereby compromises the Archie estimates (Archie water saturations will be high). In terms of the Pickett Plot, data points shift to the Southwest, and so it's good practice to annotate one's Pickett Plot with SP / GR / Rhob-NPhi / etc in the 'z' direction.

Roberto Aguilera (1990) developed variations of the shaly sand Pickett Plot which offer the option of 'countering' the Southwest shift of data. He found that all published methods

Continued on page 11...

Formation Evaluation: Carbonate versus Sandstone ... continued from page 10

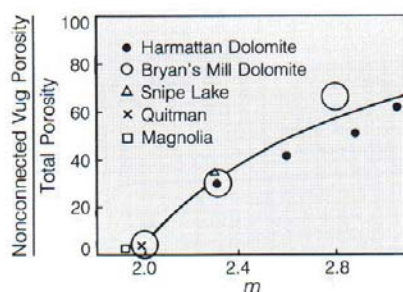
for evaluation of laminar, dispersed and structural clays could be written as $R_t/A_{\text{shale}} = a R_w \Phi(\text{effective})^{(-m)} S_w^{(-n)}$ where A_{shale} is model dependent (Indonesian, Dual Water, Waxman Smits, etc....).

If one then displays R_t/A_{shale} vs $\Phi(\text{effective})$, as compared to measured resistivity vs porosity – Figure 7 & 8, there is a graphical compensation for clay conductivity effects on the resulting (pseudo) Pickett Plot.

As compared to sandstones, the carbonate pore system is less often affected by clay conductivity and one is most commonly faced with variations in the pore size distribution / connectivity (Figure 9 and John Rasmus, 1986)

Carbonate versus Sandstone
Figure 9

- Unconnected *vuggy* pore space vs total porosity
- $m \sim 2$ for interparticle porosity
- $m \sim 3$ for porosity that is 60% vuggy



F J Lucia: Petrophysical Parameters Estimated from Visual Descriptions of Carbonate Rocks: A Field Classification of Carbonate Pore Space, Journal of Petroleum Technology 35 (1983): 629 - 637
Schlumberger Technical Review, Volume 36 Number 3

Now the Pickett Plot 'z' axis should be annotated with attributes [$\rho(\text{sonic})$ vs $\rho(\text{Rho}/N\Phi)$, etc] that will highlight this characteristic, if present. At the extreme, one may need to supplement the porosity – resistivity evaluation with alternative techniques (image logs, dielectric log, pulsed neutron log, nuclear magnetic resonance, etc).

Schlumberger has published, in their Technical Review / Oilfield Review, three articles which provide a more in-depth review of Archie's equation.

- Archie's Law: Electrical Conduction in Clean, Water-bearing Rock. The Technical Review: Volume 36 Number 3
- Archie II: Electrical Conduction in Hydrocarbon-Bearing Rock. The Technical Review: Volume 36 Number 4
- Archie III: Electrical Conduction in Shaly Sands. Oilfield Review: Volume 1 Number 3

In many regards, the key distinction between sand and carbonate, is then one of accounting for clay conductivity 'short circuits' versus variations in pore system tortuosity associated with changes from intercrystalline / interparticle to vuggy porosity.

Three- and Four-Dimensions

Development of a single-well evaluation, even one that involves core, is only the beginning. Formation attributes derived from individual well analyses must fit into the prevailing geologic framework, well to well: the static model.

Time-lapse monitor logs and production data must be understandable within the context of the static model: the fourth dimension.

It's entirely possible that the static model will evolve as more wells, and perhaps routine and special core data, become available, which brings one to an iterative loop (Ballay, 2000).

Some Companies (Petronas, for example) have a policy of re-examining all Fields on a scheduled, rotating basis, taking a fresh look at all (historical and newly acquired, simultaneously) data. In these time-lapse efforts it's important to realize that even the routine tools may yield information that was not extracted the first (or second) time around. Without meaning to discount the value of new, high-tech tools in any way, there are many examples of significant advances resulting from multi-well studies based upon 'routine' tools

In both the sandstone and carbonate worlds, there is tremendous value in multi-well evaluations and time-lapse comparisons, on a re-occurring schedule.

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Formation Evaluation: Carbonate versus Sandstone ... continued from page 11

Summary

Evaluation of sandstones and carbonates typically bring different issues to the forefront. As the geoscientist of today moves from one province to another, it's worthwhile to summarize those key differences, and thereby focus one's attention.

This particular contrast has addressed the routine wireline tools. Additional ideas and techniques may be found on-line, at the following links.

<http://www.kgs.ku.edu/Gemini/>

<http://www.spec2000.net/index.htm>

The authors welcome comments and additional perspectives, which may be directed to their e-mail address

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We plan to next address specialty tools, and suggestions / observations / references for that effort would also be appreciated.

Acknowledgements

We appreciate Roberto Aguilera, Ross Crain, John Doveton, Jerry Lucia, John Rasmus and Chris Smart's review of this effort. Roberto's comments about shaly sand Pickett Plots, and Ross' experience with shaly sand porosity estimates brought forward perspectives and ideas that were not in the original version, but have now been incorporated.

Much of this material was extracted from the Carbonate Petrophysics course that was developed, and is taught by, Gene Ballay. He gratefully acknowledges the 47 contributors to that effort, who are individually listed in the Introduction Module of the Course.

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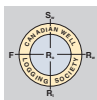
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A Response to Myth-Interpretation #4

A Contribution on Density Log Interpretation

Mauro Gonfalini

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Recently I was downloading the digital version of InSite, the very nice CWLS bulletin and read with interest Ross Crain's columns "Myth-Interpretation". In particular, I was attracted by the argument of the last issue: the density log.

If you do not mind, I would like to add some issues to the problem of interpretation of density logs in complex environments and, specifically, in complex formation mineralogy. I would like to share with you my experience in the interpretation of the density log in clastic reservoirs in Italy which, due to the complex geological and structural setting of the region, may present a very wide variety of textures and compositions.

In this context, the average grain density may vary a lot from very "heavy" to very "light" with respect to the usual value of 2.65 g/cc for quartz.

In Sicily and, generally, in Southern and Central Italy we have a lot of gas bearing reservoirs in quartzitic sands or sandstones. A typical example is the orthoquartzitic, gas and condensate bearing sandstones of the Gagliano Field showing an average grain density of 2.65 g/cc. In contrast, the main gas bearing sandstone reservoirs of the Po valley and the Northern Adriatic Sea, generally present an average grain density ranging between 2.68 to 2.75 g/cc.

Typical textures of these reservoir sections change from coarse sands to fine silts and the mineralogical composition, due to the erosion of a large variety of rocks belonging to the Alps and the Apennines chains, comprises quartz (generally no more than 40% in weight), various types of feldspars, micas, carbonates (both limestone and dolostone). In rocks of such complicated mineralogy, the natural radioactivity gamma ray log is often not an appropriate indicator of clay content due to the presence of radioactive minerals in the clean reservoir sections (i.e. micas).

Moreover, the presence of very thin beds and the gas effect further complicates the log interpretation of wireline logs in this region.

A good example of "heavy" matrix density of these sandstones is the Settala reservoir in Fig. 1 (source Schlumberger WEC Italy 1987), where, in the clean aquifer section (1325 – 1353 m), there is a strong ("shale like") separation between neutron and density logs caused by the high grain density of the reservoir rock.

In contrast to the "heavy" mineral reservoirs, we have observed numerous anomalies on density logs in the Adriatic Sea associated with anomalously "light" matrix densities. These anomalies were caused by the presence of peculiar rocks such as cinerites, diatomites, or rocks mainly composed of specific minerals such as cristobalite.

These rocks rarely resulted in hydrocarbon bearing reservoirs. However, due to the anomalously low density, very often they were the cause of the presence on seismic lines of so called "bright spots", often interpreted as gas bearing reservoirs.

Cinerites are composed of more or less thick layers of volcanic ashes hosted in thick shale sections and characterized by the presence of large volumes of very low specific gravity volcanic glass. The average porosity of these layers ranges between 40 and 45 pu. and the measured RHOB can be as low as 1.80 – 1.85 g/cc in water saturated sections and 1.60 – 1.70 g/cc when partially gas saturated. In any case the quality of these reservoirs is quite poor and the permeabilities are in the range between 0 and 2 mD from the very few core measurement available.

Due to the chemical composition of the ashes (rhyolite), GR values in front of cinerite levels are generally much higher than the hosting shales, while neutron readings are very similar to those of the hosting shales. The cross-over of density and neutron curves, mimicking a "gas effect", results from the anomalous low density values of the rock, not from light hydrocarbons.

Cinerite layers are very often used as regional markers and therefore they allow regional correlation among wells.

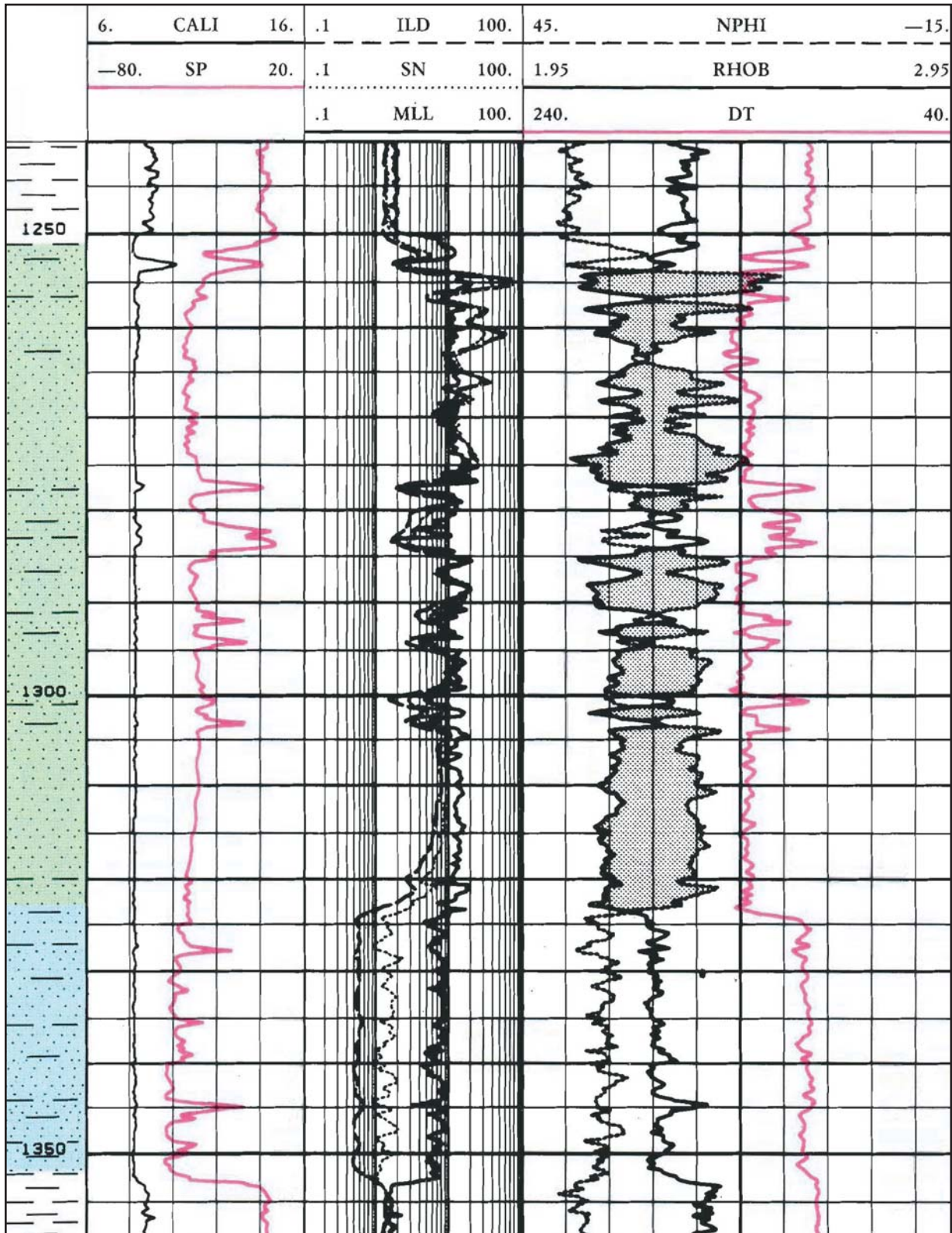
Diatomite is a chalk-like, soft, friable, earthy, very fine-grained, siliceous sedimentary rock, usually light in colour, composed of the skeletons of siliceous algae. Here density anomalies are related to the presence of this very light amorphous siliceous material.

Available examples of log responses in diatomite layers in the off shore Central Adriatic Sea show, in thick layers, RHOB values as low as 1.75 g/cc, while GR and neutron measurements are very similar to the ones of the host shales. Due to the peculiar texture of these formations, BHC acoustic responses are anomalously high, often exceeding 190 msec/ft. Again, average porosities measured on few cores range between 40 and 45 pu. (these formations are generally deposited at shallow burial depths), the quality of this reservoir type is very, very poor (i.e. very low permeabilities).

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A Response to Myth-Interpretation #4 ... continued from page 14



Well Settala 1 shows classic gas cross-over in gas-bearing sand (shaded area) and separation between density and neutron logs in clean water sand due to the effect of heavy minerals. Note also gas effect on the sonic travel time (red curve at right). Illustration from Schlumberger Well Evaluation Conference, Italy 1987.

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Myth-Interpretation ... continued from page 15

Due to very low permeabilities of these formations, multiple resistivity measurements (typically DIL/SFL) do not show presence of invasion and the SP is flat because of insufficient contrast between R_w and R_m .

Again the presence of these low density layers was the origin of "bright spots" in seismic profiles in some offshore Central Adriatic Sea fields, not related to gas accumulations.

A third cause of anomalous density responses in the same region is the presence of a shaly layer rich in cristobalite, a high temperature, amorphous modification of silicon dioxide (SiO_2), characterized by a specific gravity around 2.30 g/cc.

In the early eighties it was reported that the presence of cristobalite for an amount of about 30% in weight in a shaly,

8 m thick level in a well was producing a cross-over between density and neutron logs typical of a gas effect. The level was tested and produced only salty water. Of course the gas effect was only generated by the very low density of the level and a careful analysis of the other well information (lack of gas shows, lack of gas effect on BHC acoustic measurements, lack of evident resistivity anomalies), would have better directed the well log analyst to a more correct integrated interpretation of the well data available.

Unfortunately all these last examples are unpublished but I do have in my library all the related documentation if necessary.

About the Author



Mauro Gonfalini has been the Senior Professional Formation Evaluation of ENI E&P since December 2003. In this position he was mainly responsible for keeping ENI E&P in a position of excellence with respect to Formation Evaluation technologies, monitoring and improving the Formation Evaluation process applied by the company and enhancing the integration of the different disciplines in the process itself.

He joined ENI AGIP in 1975 holding a degree in Geology from Università Statale of Milan. Since that time he was involved in well log acquisition and interpretation in worldwide operational E&P projects as well log analyst and petrophysicist.

In the last few years, Mauro was the reference person for the development of the R&D Technology Plan of ENI E&P in the area of Petrophysics and Well Logging, a technical leader of R&D projects dedicated to the effective application of innovative well data acquisition and interpretation technologies, technical leader of several multidisciplinary studies covering a large variety of reservoir types.

Mauro has also been deeply involved with the organization and delivery of educational programs in Petrophysical Interpretation of well logs, both in internal courses and with Academia. Mauro is author or co-author of more than 20 technical papers in the area of well log interpretation. As an active member of the Society of Petrophysicists and Well Log Analysts (SPWLA) he received in 1999 a Technical Achievement Award and served the Society as Distinguished Speaker.

As an active member of SPE, Mauro served for several years in the Board of the Italian Section as Program Chairman, as Committee Member of several SPE worldwide events, Chairman of the SPE Well Logging Committee (ATCE 2000), Chairman of a Forum on Fractured Reservoirs (Europe Series, 2000), Chairman of the ATW on Management of Petrophysical Uncertainties (Europe Series, 2001) and he served for several years as Technical Editor of the SPE RE&E Bulletin.

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Advances in Surface Geochemical Techniques

By Robert O. Potter and Harry S. Anderson

Summary

Vertical migration of volatile compounds from oil and gas reservoirs can be sensed using surface geochemical techniques. Since 1930, geologists exploring for oil and gas have developed and tested methods which can image hydrocarbon-filled reservoirs by measuring near-surface parameters. The traditional techniques have included direct soil analysis, active soil gas measurement and microbial techniques.

Traditional techniques have historically suffered from some limitations. These include the poor adsorptivity of soils, sampling difficulty due to poor soil permeability, low analytical sensitivity, limited data sets of C_1 - C_5 hydrocarbons (methane-pentane), problems resulting from variability in the site soil and meteorological conditions, and interference from biologically generated methane.

All of these limitations can be overcome by a recent technique based on the time-integrated collection of hydrocarbon vapors via a buried, **passive sorbent-based collector** over an extended period of time (typically days). The passive soil vapor sampling device results in direct detection of surface hydrocarbons potentially related to microseepage from reservoir hydrocarbons.

Vertical Migration

All near-surface methods rely on the documented physical phenomena of vertical micro seepage of hydrocarbons from the reservoir (Klusman & Saeed, 1996). There is a large body of empirical evidence in the literature that supports microseepage over reservoir hydrocarbons. Klusman and Saeed cite the following five examples:

1. The increase in nonmethane light hydrocarbons as a reservoir is approached during the mud logging of many wells;
2. The increase in C_2/C_1 , C_3/C_1 and C_4/C_1 ratios in soil gas over hydrocarbon reservoirs;
3. The sharp lateral changes in these ratios at the edges of the surface projections of hydrocarbon reservoirs;
4. The similarity of stable carbon isotopic ratios for methane in soil gases to those found in underlying hydrocarbon reservoirs; and
5. The undetectable amounts of C_{14} in soil gas hydrocarbons and secondary oxidation products suggesting ancient sources of carbon.

It should be noted that microseepage differs from macroseepage where a reservoir has been breached and hydrocarbons are shunted along a fault. With microseepage, the reservoir seal is still in effect but the reservoir pressure and high hydrocarbon concentration within the reservoir creates a natural driving force. Laws of nature dictate that all systems move from high concentration and high pressure found in the reservoir toward the low concentration and pressure found at the surface of the earth (Figure 1). While the reservoir seal is effective in holding more than 99% of the hydrocarbons in the reservoir, the seal is not completely impervious. Grain boundaries and micro-cracks throughout the overburden above the reservoir provide pathways for the movement of the hydrocarbons.

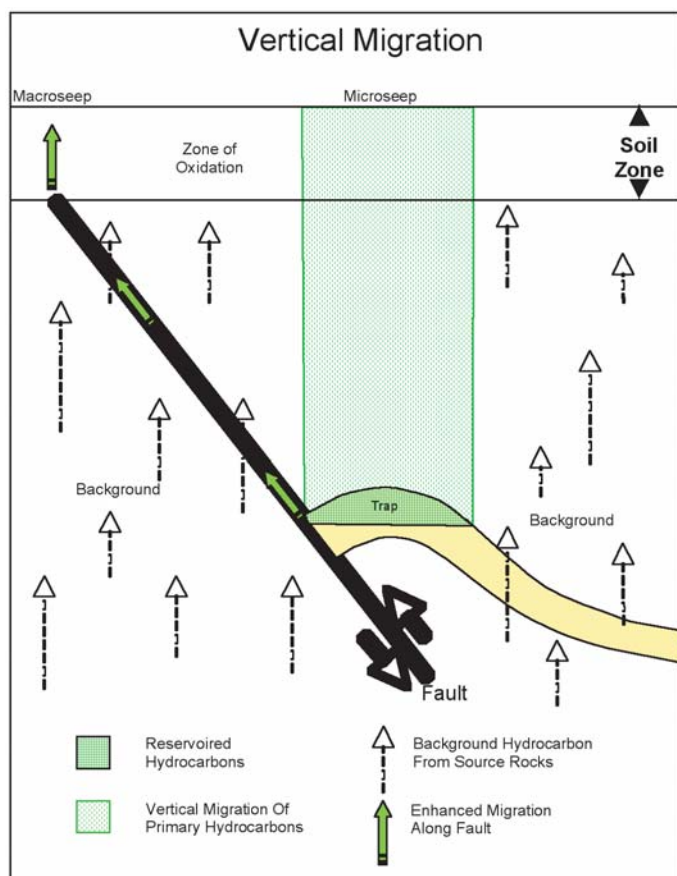


Figure 1: Concept of surface microseepage (Adapted from Potter et al, 1996)

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Advances in Surface Geochemical Techniques ... continued from page 18

It has been shown that over pressurized demand gas storage reservoirs, light hydrocarbons increase in the soil gas and have similar carbon isotope compositions to the reservoir gas (Coleman et al, 1977).

There are several physical mechanisms that aid in driving these hydrocarbons toward the surface of the earth at rates on the order of meters/day. The most significant of these possible mechanisms are:

1. **Micro-buoyancy:** Relative density differences between hydrocarbons and water or soil.
2. **Isolated methane-driven fractures:** Buoyancy driven propagation of fractures from depth which carries hydrocarbons.
3. **Gas entrainment:** Gases rising toward the surface carry hydrocarbons.

A Revolutionary Exploration Technique

Passive Sorbent-Based Collector

After examining the disadvantages of direct soil analysis, active soil gas, and microbial surface geochemical techniques, it is easy to understand why standard techniques of surface geochemical exploration are not widely accepted in the exploration process by the industry. Adequate hydrocarbons are found in less than one out of five exploration areas, and the standard surface techniques have limited data sets with poor predictability. They have poor sensitivity and are subject to variances in soil character over the site. Even though the standard techniques may be relatively inexpensive, their value is too limited to be cost effective.

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Advances in Surface Geochemical Techniques ... continued from page 19

The technique based on a **passive sorbent-based collector** (the GORE™ Module) was developed to eliminate or minimize the limitations of the early surface techniques. The design and application of the passive sorbent-based technique has focused improvements in four areas:

1. The collector was designed to eliminate issues with soil adsorptivity and non-uniformity;
2. The deployment method minimizes the variation in both soil conditions and ambient weather conditions;
3. The analysis method was improved to expand the data set and the method significantly boosts sensitivity allowing for the detection of hydrocarbons through thick sections of volcanics, salt and anhydrite; and
4. A multivariate analysis technique was developed to utilize the robust data set and improve the imaging of charged hydrocarbon reservoirs of all types.

The collector consists of duplicate sorbent collection units, “sorbents”, composed of hydrophobic adsorbent specifically designed to collect C_2 - C_{20} hydrocarbons and carefully selected for their affinity for a broad range of volatile and semi-volatile organic compounds (VOCs and SVOCs), while minimizing uptake of water vapor (the principal soil gas constituent in most areas). While compounds don’t need to be gases to have a measurable vapor pressure and exist as a component of soil gas, hydrocarbons greater than C_{20} typically have vapor pressures too low for molecules to be found in the gaseous state. The engineered adsorbent’s hydrophobic nature minimizes competition with water vapor in sites with variable moisture content.

The sorbers are sheathed in a vapor-permeable retrieval cord which is constructed of an inert, hydrophobic, microporous, expanded polytetrafluoroethylene membrane. A loop at the top of the cord is used as a means of tying the collector to a string for installation and retrieval. The membrane has micropores sized to keep out water to depths of 7-10 meters yet allow free diffusion of gases to the engineered adsorbent. The microporous structure also protects the granular adsorbents from physical contact with soil particulates ensuring a consistent mechanism for collection of organic compounds (vapor-phase transfer only). Figure 2 shows the GORE™ Module.

The collector is easily deployed by inserting it into narrow diameter holes pounded or drilled into the ground to about 0.6 meters depth. Field installation and retrieval is fast, easy to accomplish and low cost and allows economical deployment over

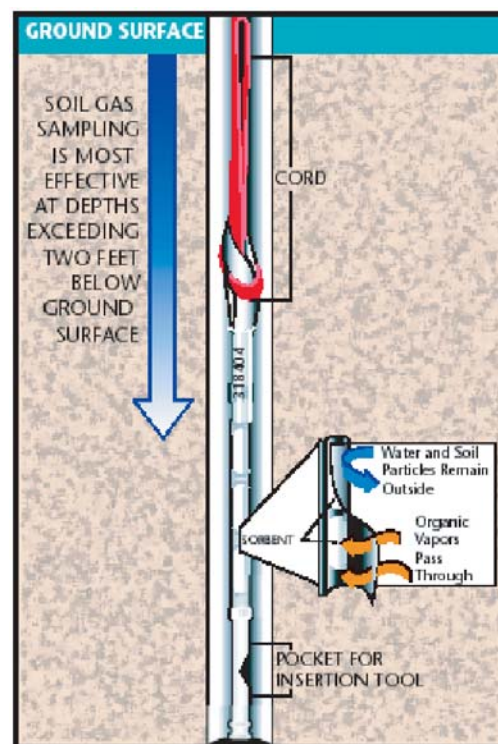


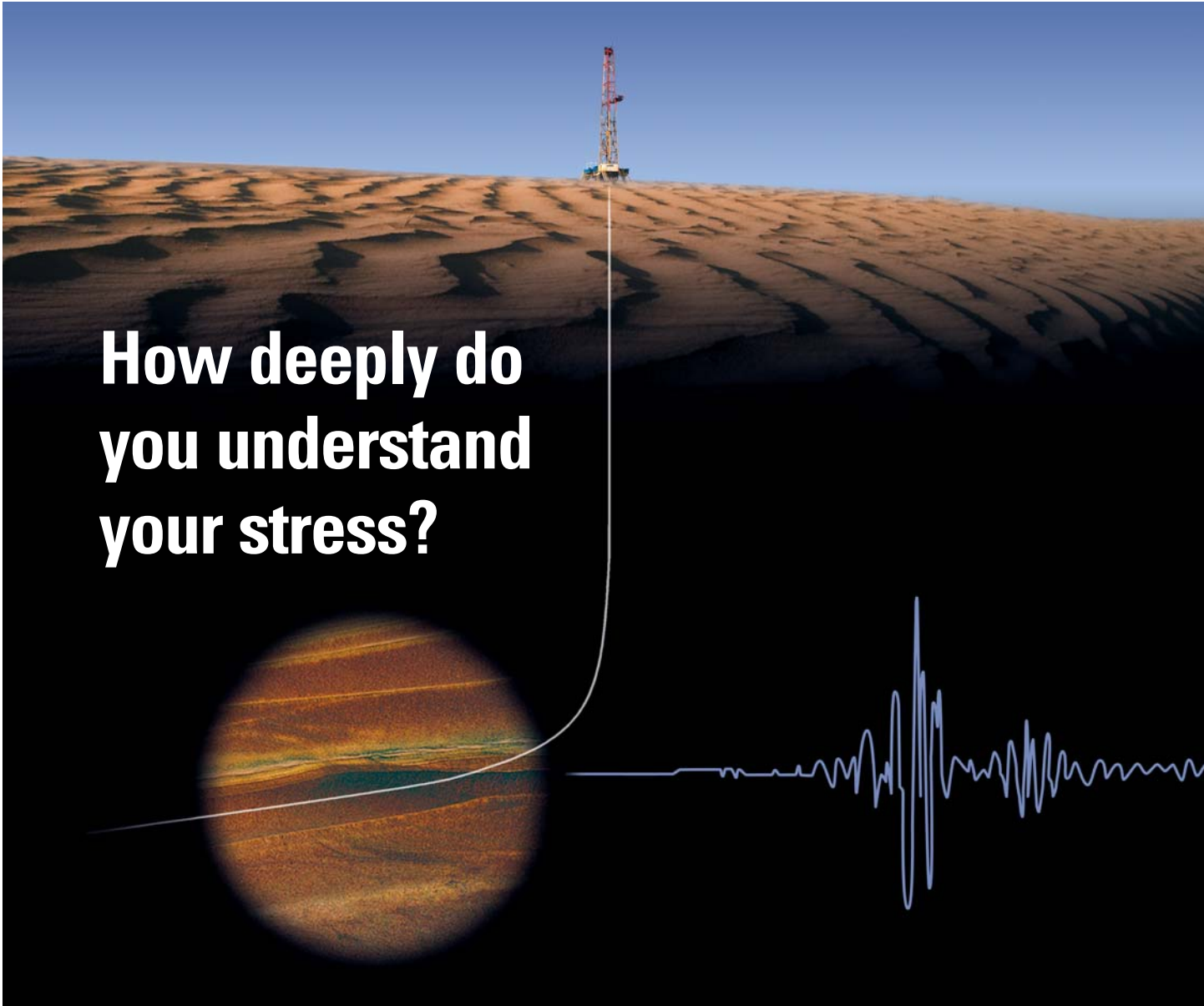
Figure 2: GORE™ Module (Passive Sorbent-Based Collector)

difficult terrain, with no disruption to landowners or the environment. The collector is left in the ground for a period of about 17 days, during which it passively collects volatile compounds in the soil and vertically migrating from the reservoir. This extended period smoothes out potential variations due to atmospheric changes, solar heating, rain, or other meteorological events. Additionally, the longer time boosts the hydrocarbon signal on the sorbers by continually collecting vapors while in the ground. The collector is retrieved by hand and returned to the laboratory for analysis and data processing.

Geochemical Survey Design

Prior to initiating a survey, specific survey objectives are established with the client and an appropriate sampling scheme and modeling strategy are identified. Information relating to target size and type, any preferred reservoir orientation characteristics, such as a channel sand, and the existence of analogous production and specific well characteristics and production history are important factors in developing an appropriate survey design. Of paramount importance is what decisions are expected

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Advances in Surface Geochemical Techniques ... continued from page 20

to be made based on the geochemical results. The survey design must be sufficient to support or minimize the uncertainty of decisions affecting the "next step" in the exploration program.

Sampling plans typically follow a grid pattern with regular or variable spacing of collectors, sampling traverses, or a combination of both (Figure 3). Sample spacing generally ranges from 300 meters to one kilometer. Appropriate wells are selected for the purpose of modeling surface geochemical character over analogous production and dry/background areas.

Analytical Procedure

To quantitatively and directly measure the hydrocarbon vapors collected by the collector, a state-of-the-art TD/GC/MS analytical method with sensitivity in the parts per trillion range has been developed. It uses a thermal desorber (TD) to transfer the compounds on the adsorbent into a gas chromatographic column (GC) and to separate each of about 82 compounds from C₂-C₂₀. A mass spectroscopy (MS) is used to positively identify and quantify each compound (Table 1). As a result of the engineered adsorbent, the long deployment time, and the sensitive GC/MS, this method can collect and measure concentrations equivalent to about 1 nanogram (10E-9 grams) or about 1 part per trillion in the soil gas (ppt). This is three orders of magnitude better than the best alternative methods.

Before each analytical run sequence, two instrument blanks, a sampler exposed to a BFB (bromofluorobenzene) standard, and a method blank are analyzed. A method blank and a BFB standard are also analyzed after every 30 samples and/or trip blanks. Calibration standards are analyzed at the beginning of each run, after every 30 samples and/or trip blanks, and at the end of the run sequence. Compound identification is based on the presence of appropriate target compound mass fragments within a specific retention-time window, as determined through use of reference standards.

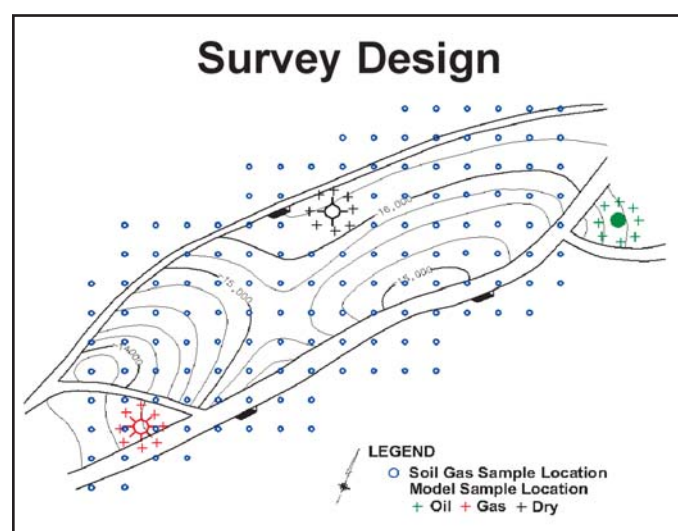


Figure 3: Normal surface geochemical survey design relative to prospect maps

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Advances in Surface Geochemical Techniques ... continued from page 22

Table 1: Target Analytical List

Typical Petroleum Constituents			
Carbon number in ()			
Normal Alkane	Iso-alkane	Cyclic Alkane	Aromatic & PAH*
Ethane (2)	2-Methylbutane (5)	Cyclopentane (5)	Benzene (6)
Propane (2)	2-Methylpentane (6)	Methylcyclopentane (6)	Toluene (7)
Butane (4)	3-Methylpentane (6)	Cyclohexane (6)	Ethylbenzene (8)
Pentane (5)	2,4-Dimethylpentane (7)	cis-1,3-Dimethylcyclopentane (7)	m,p-Xylenes (8)
Hexane (6)	2-Methylhexane (7)	trans-1,3-Dimethylcyclopentane (7)	o-Xylene (8)
Heptane (7)	3-Methylhexane (7)	trans-1,2-Dimethylcyclopentane (7)	Propylbenzene (9)
Octane (8)	2,5-Dimethylhexane (8)	Methylcyclohexane (7)	1-Ethyl-2/3-methylbenzene (9)
Nonane (9)	3-Methylheptane (8)	Cycloheptane (7)	1,3,5-Trimethylbenzene (9)
Decane (10)	2,6-Dimethylheptane (9)	cis-1,3/1,4-Dimethylcyclohexane (8)	1-Ethyl-4-methylbenzene (9)
Undecane (11)	Pristane (19)	cis-1,2-Dimethylcyclohexane (8)	1,2,4-Trimethylbenzene (9)
Dodecane (12)	Phytane (20)	trans-1,3/1,4-dimethylcyclohexane (8)	Indane (9)
Tridecane (13)		trans-1,2-Dimethylcyclohexane (8)	Indene (9)
Tetradecane (14)		Ethylcyclohexane (8)	Butylbenzene (10)
Pentadecane (15)		Cyclooctane (8)	1,2,4,5-Tetramethylbenzene (10)
Hexadecane (16)		Propylcyclohexane (9)	Naphthalene (10)
Heptadecane (17)			2-Methylnaphthalene (11)
Octadecane (18)			Acenaphthylene (12)

Byproduct and Alternation Compounds

Included in this method to provide a substantial inventory of the geochemical system in the surface soil zone

Alkane	Alternation / ByProduct	Biogenic	NSO*
Ethene (2)	Octanal (8)	alpha-Pinene	Furan
Propene (3)	Nonanal (9)	beta-Pinene	2-Methylfuran
1-Butene (4)	Decanal (10)	Camphor	Iodomethane
1-Pentene (5)		Caryophyllene	Carbon Disulfide
1-Hexene (6)			Benzofuran
1-Heptene (7)			Benzothiazole
1-Octene (8)			
1-Nonene (9)			
1-Decene (10)			
1-Undecene (11)			

*PAH = polyaromatic hydrocarbons, NSO = nitrogen, sulfur, oxygen compounds

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Advances in Surface Geochemical Techniques ... continued from page 23

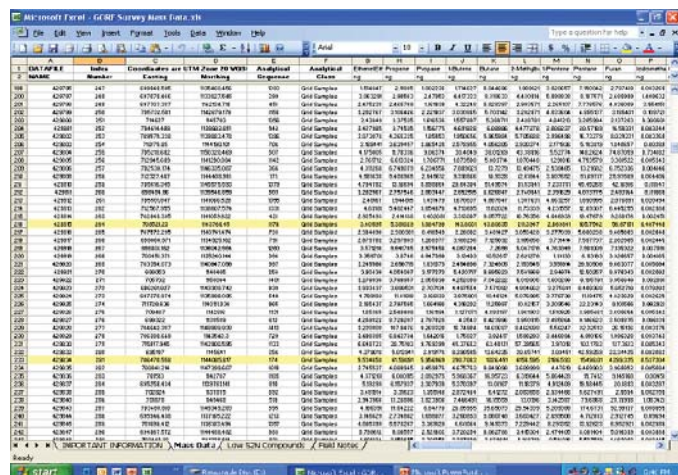


Figure 4: Mass Spectrometer Data

Trip blank samples which are shipped with the survey modules and are selected at random by personnel are also analyzed. Prior to data processing, trip blank, method blank, inventory blanks and instrument blank data are reviewed to identify potential ambient exposures, or laboratory conditions which may affect data quality.

The mass spectral data for the compounds are presented to the client in the form of an Excel® spreadsheet (Figure 4) forming a data base that could potentially be re interpreted in the future.

Rather than five compounds from C₁ to C₅ as measured in soils or soil gas, the 82 different compounds from C₂ to C₂₀ allow differentiation between the fingerprints of hydrocarbon compounds naturally found in the soil over uncharged areas from the fingerprint of hydrocarbon compounds found over charged reservoirs. Further, the robust data set allows differentiation of compounds found in dry gas, wet gas, condensate, and all types of oils (Figure 5).

WCSB Gas Separation Example

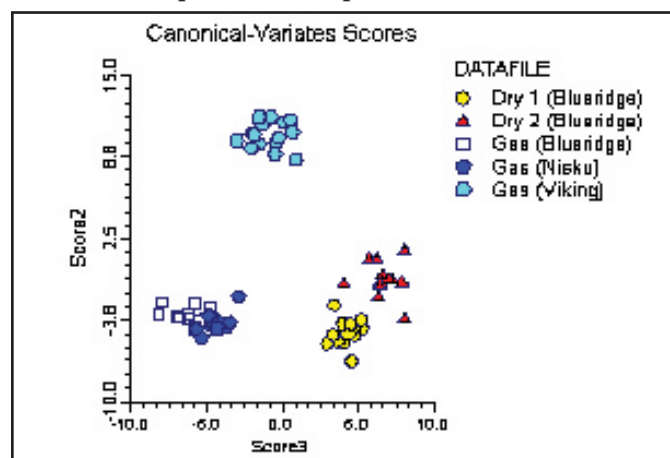


Figure 5: Demonstration of the separation of Cretaceous and Devonian gas zones in the Western Canadian Sedimentary Basin

Data Processing and Modeling

The technique incorporates statistical processing and modeling of the complex geochemical signatures obtained for each sample. Some of the processes used include hierarchical cluster analysis and linear discriminant analysis.

Hierarchical cluster analysis (HCA) is often called an “unsupervised” multivariate technique, since no additional information other than the data itself is required to perform the operation. That is, it is not necessary to identify “end-members” of the data or qualify the data in any manner in order to perform subsequent comparison or evaluation of the data, as is the case with some multivariate classification techniques. HCA proceeds by grouping samples of like composition according to the

Continued on page 25...

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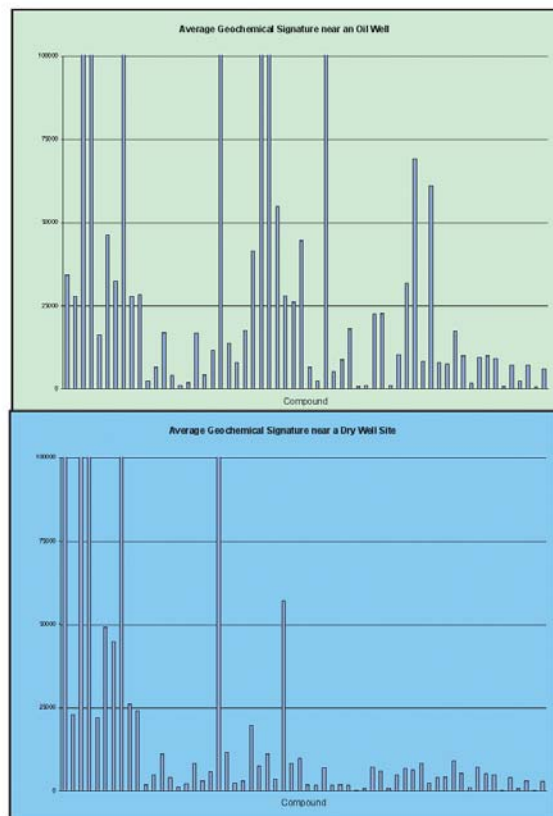
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Example Model Site Signatures

Oil vs. Dry
Middle East Project, 35° API
Scale 0 - 100K ion count



Gas-Condensate vs. Dry
Middle East Project, GOR>6,500
Scale 0 - 40K ion count

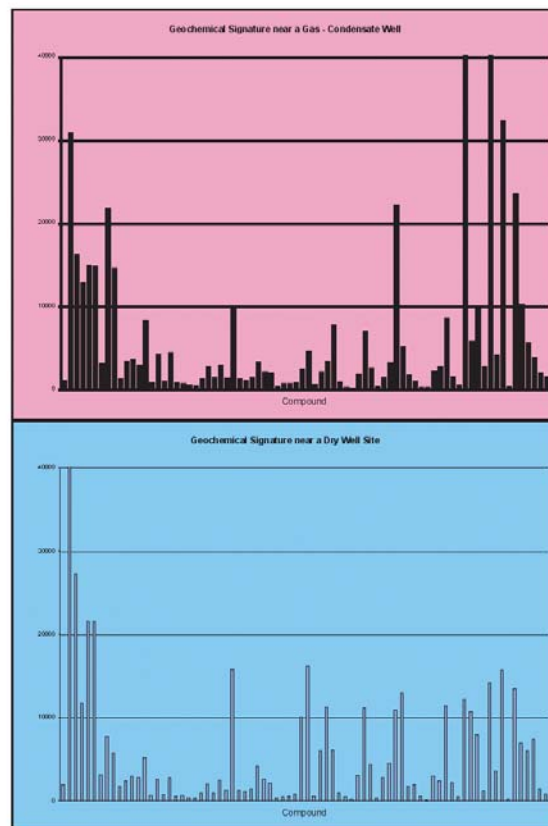


Figure 6: Comparison of surface geochemical compound signature of hydrocarbon-bearing to dry wells. The blue charts in both cases represent Dry Well locations. The green chart represents an oil well, and the pink chart represents a gas/condensate well.

values of all input variables. The result is a list of subsets of samples of the data which are alike (forming “clusters” of similar samples). Since the input variables of the data are in the form of hydrocarbon compound intensities, the clusters are subsets of chemically similar samples. The HCA method is used to determine the structure of a set of data when no other geological or geophysical information for the prospect is available. The results of HCA may be used to further classify the samples of the data (i.e.; whether particular samples show petroleum hydrocarbon influence).

Linear discriminant analysis (LDA) is a multivariate data classification technique. At least two subsets of input samples must be identified as belonging to separate groups (with any such “group” of samples presumably representative of a particular physical influence in the sampled environment). The LDA technique will then find the best separation of the groups in a minimum residual sense, in terms of the input variables for the samples. Since the input variables are of a chemical nature, the separation of the sample groups is expressed as a chemical dif-

Continued on page 26...



Advances in Surface Geochemical Techniques ... continued from page 25

ference between the groups. The classification of samples of unknown influence is then performed; each unknown sample is compared to the identified groups of samples and a probability of match to each sample group is calculated. Therefore, if a group of samples is identified as petroleum-influenced, and another group of samples is identified as being like geochemical background, DA will statistically describe the difference between these two groups. The comparison of unknown samples to these two groups will yield for each unknown sample a probability of being like the petroleum influence, as well as a probability of being like the geochemical background influence (Figure 6).

Conclusion

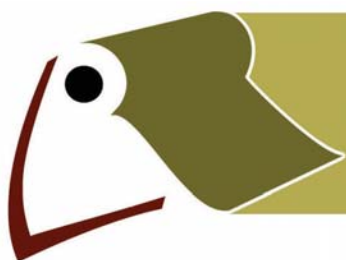
New developments in passive collectors and higher sensitivity GC/MS analysis can produce results in all exploration sites including desert, forest land, jungle, swamps, shallow bays, and

permafrost terrains. When this extensive data set is analyzed using multivariate statistical techniques, it is possible to identify a "fingerprint" of compounds at the surface that relate to charged reservoirs versus background (uncharged reservoirs). When plotted on a map, these images of the reservoir charge can be integrated with other G&G data to maximize drilling success.

References

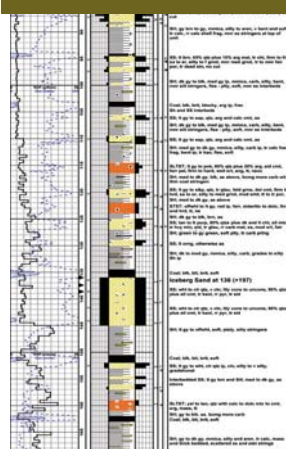
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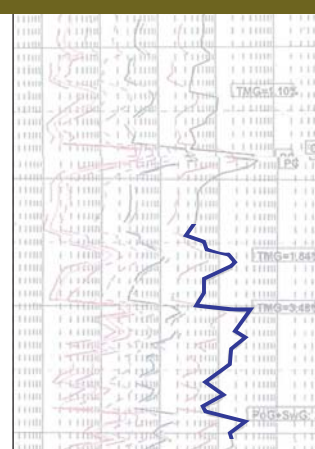
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Other Readings

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About the Authors



Bob Potter is a professional explorationist and manager with over 35 years of domestic and international experience... From 1982 to 1997, Bob worked for Alberta Energy Company Ltd. where he held various positions of increasing responsibilities in the domestic and international departments. For 2.5 years, he worked for Talisman Energy seconded to Sudan as a Team Leader. He has experience in Argentina, Thailand and the Sudan. Currently, Bob is consulting for local domestic companies generating exploration prospect portfolios in the Western Canadian Sedimentary Basin.

Bob has participated in the organization of the World Petroleum Congress in 2000, the planning of the Calgary Millennium Park in 2000, the preparation of the Upper Cretaceous chapter for the 2001 Natural Gas Potential in Canada report and the creation of the Eau Claire Community Association. Currently he is the Director for the CSPG International Division.

Harry Anderson, a chemical engineer with a BSCE degree from U of Delaware in 1971, has been engaged in Research & Development, Marketing, and new business management for 25 years. For the last 4 years, Harry has lead a team of chemists and geologists offering an advanced geochemical tool used to detect, characterize and delineate geochemical anomalies related to environmental pollution, pipeline & tank leaks, petroleum reservoirs, and precious mineral deposits.



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Bulletin 2006-22

September 1, 2006

EUB Bulletin 2006-22 • 1

New Well Logging Requirements – Surface Casing Interval

The Alberta Energy and Utilities Board (EUB) is proposing changes to well logging requirements in an effort to gain more information on near surface geology. The intention is to add logging requirements for the surface casing interval for all new wells drilled in the province after November 1, 2006. By way of this bulletin, the EUB is seeking feedback on this proposal, specifically with respect to alternatives that might provide an equal or higher level of information.

Background

The significant increase in exploration and development drilling targeting the shallow geologic column has led to increasing public concern that this activity may have a negative impact on shallow aquifers.

Existing regulations do not require collection of geological information from the base of surface casing to surface. As a result, industry voluntarily collects and submits minimal data for this interval. The vast majority of geological information (geophysical well logs, core, and drill cuttings) obtained during the drilling of oil, gas, and oil sands wells covers intervals below the base of surface casing. The EUB believes additional information will greatly enhance the understanding of the geological strata behind surface casing, as it will provide valuable information for geological mapping and characterization of the shallow strata. These data will assist all parties in the evaluation of the potential impact of oil and gas activity on shallow aquifers. Improved geological mapping of the shallow strata will assist by

- improving geological understanding and identification of groundwater resources and their distribution, connectivity, and relationship to other geological units,
- improving mapping of the base of groundwater protection, and
- enhancing the ability to identify porous and/or permeable strata that may act as conduits for fluids.

New Requirements

There are a number of options for gathering additional information for this interval, such as sample collection and lithology logging; however, the EUB has determined that enhancing logging requirements is the most cost-effective means of obtaining the necessary information. The existing regulations (Oil and Gas Conservation Regulations, Section 11.140[1]) require the taking of an acceptable log to measure the resistivity and spontaneous potential of the strata from the total depth of the well to the base of surface casing, but there are no logging requirements for the surface casing interval.

The EUB is planning to implement the following minimum requirements for well logging through casing from the base of surface casing to surface for all new wells. The requirements of Section

11.140 of the Oil and Gas Conservation Regulations will be amended to require the taking of logs to measure the

- natural gamma ray response through casing from the base of surface casing to surface, and
- neutron response through casing from the base of surface casing to 25 metres below the surface (as the neutron tool is a radioactive device, to protect workers safety it cannot be run to surface).

Requests for Comments

Prior to implementing the new logging requirements, the EUB is seeking stakeholder input on the proposed additional well logging requirements. Specifically, the EUB is interested in feedback with respect to alternative measures that could be taken to collect equivalent or better information over the subject interval. Any feedback received will be considered prior to implementing a change in requirements. Comments and feedback may be forwarded by e-mail to the EUB at shallowlogging@gov.ab.ca prior to September 1, 2006.

A directive announcing the final data collection requirements for the surface casing interval will be issued subsequent to considering all feedback.

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Tech Corner – Permeability from Open-Hole Logs

Kenneth Heslop, P.Eng., LogX Inc.

kenneth.heslop@logx.ca

There are many direct and indirect measurements of porosity, but the permeability of a reservoir has until now been an elusive parameter. Some have attempted to use NMR technology to infer permeability, but that method requires extensive core data for calibration. The purpose of this paper is to present a method anyone can use to predict permeability in common reservoir rocks without the necessity of core data or expensive logging runs.

A couple of definitions are necessary to begin with. Porosity is considered here as a measure of the pore space in the rock. This excludes the water associated with clay in shale. In petrophysics we speak of this as effective porosity. Permeability is a measure of how easily fluids can flow through the rock. Therefore both porosity and permeability are characteristics of the solid medium, the rock from which we hope to produce hydrocarbons.

for the higher porosity data. Below 5 percent porosity we find one relationship does not adequately represent the permeability data. Consider that at 3 percent porosity this data suggests we could have a range of permeabilities from 0.5md to 50md. It does not seem reasonable to assume this range of data should be represented by one value, which would be slightly greater than 10md.

Before simply assuming the scatter of the permeability data is due to data errors, consider the proposed correlations in Figure #2. Here we see three different correlations, each defining permeability in terms of porosity at constant water saturation. Water saturation was introduced here as a measure of relative pore size. (We will develop that relationship in greater detail later.)

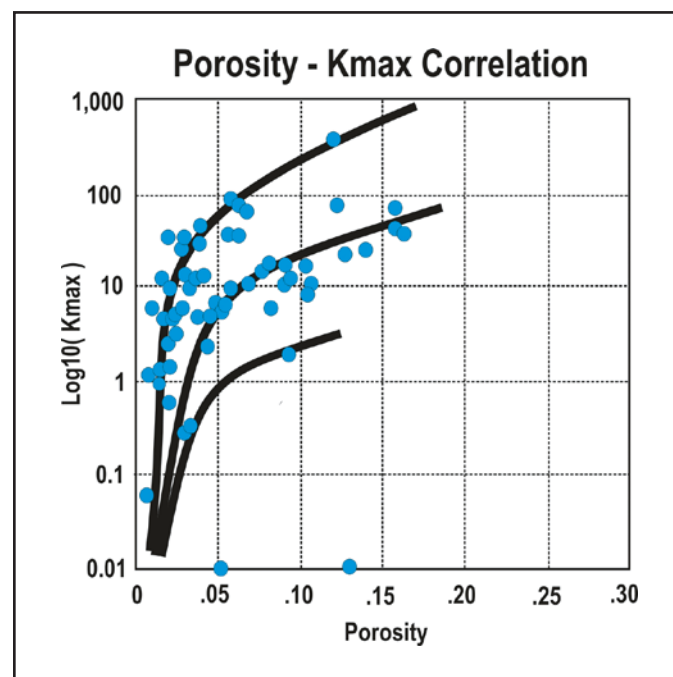


Figure #2: A Better Porosity/Perm Solution

Having introduced relative pore size, and therefore pore throat size, into the determination of permeability, it becomes clear that the permeability for any given porosity is a function of the pore throat size through which fluids must flow. In this example, we can see how at 6 percent porosity, one data trend would give a permeability of 10md, while another data trend leads to a permeability of 100md.

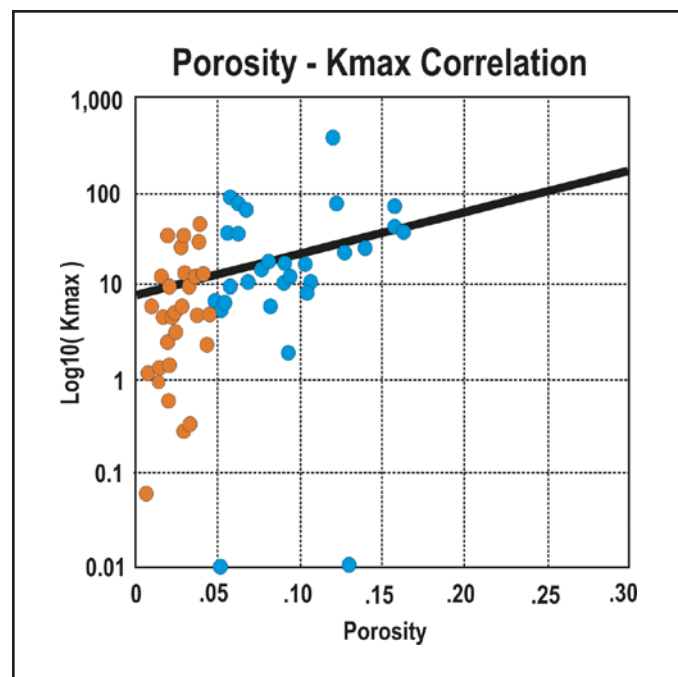


Figure #1: Common Porosity/Permeability Fit

It is common to find a linear fit suggested for porosity and permeability data, such as that shown in Figure #1. (This figure was taken from a display provided by a well-known data vendor.) Under close examination this relationship only works well

Permeability from Open-Hole Logs ... continued from page 30

Henry Darcy in Dijon

Henry Darcy developed the equation for flow in 1856 while preparing a report on the water supply for Dijon, France. He expressed flow (Q) in terms of permeability, area, length, fluid viscosity, and pressure differentials.

$$Q = -\frac{KA}{\mu} \times \left[\frac{\Delta P}{\Delta l} \right]$$

This is illustrated in Figure #3 below.

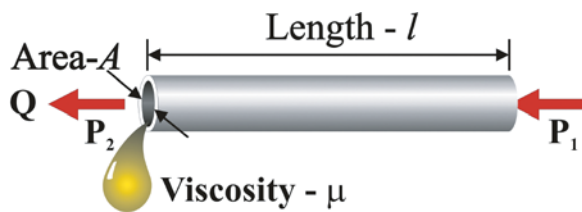


Figure #3: Darcy's Flow Model

Rearranging this equation, we have permeability in terms of flow.

$$K = \frac{1}{A} \times \left[\frac{-Q\mu}{\Delta P / \Delta l} \right]$$

When we consider the permeability of a reservoir, the fluid properties are constant, flow rate and pressure differential are linked, leaving permeability to be a function of Area. It is then interesting to note that the unit of permeability is the Darcy, which is $9.87 \times 10^{-9} \text{ cm}^2$.

Applying the Theory to Rocks

How then do we apply this theory to reservoir rocks? To begin with it is obvious we cannot either measure or calculate every pore throat in the reservoir. Every pore throat will be slightly different than the next. But we do observe different permeabilities in reservoir rocks, and hopefully we can develop a relationship to correlate the overall permeability of a formation to some reservoir property we can measure.

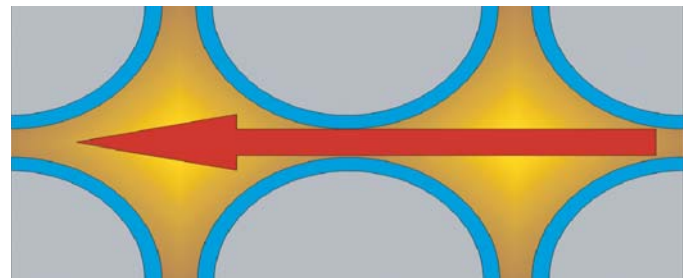


Figure #4: Permeability is a Function of Pore Throats, not Pore Volume.

While it is plain that permeability in granular or crystalline rock is a function of the pore throat cross-sectional area, we don't have an easy method to measure that area. Besides, every pore throat will be different, and permeability will be the function of the average pore throat cross-sectional area. Therefore we need a method of determining the relative pore throat area, and a relationship between that area and permeability.

It is not difficult to see that pore throat area is a function of the pore sizes ... the larger the pore, the greater the radius of the pore throat. Now consider the following cases in Figure #5: on the left is an illustration of a large pore, while on the right are four smaller pores. The pores on the right were drawn to represent pores containing the same total volume as the one large pore on the left. In both cases the thickness of the irreducible water layer is the same (0.1 units,) but the fraction of the pore volume occupied by water (S_w) is significantly different. Combining porosity and water saturation gives us an indication of relative pore size. Here we use $(1-S_w)$ because we are interested in the volume not filled with water. Thus we have a measure of relative pore size, but is that enough to resolve the relationship to permeability?

Permeability from Open-Hole Logs ... continued from page 31

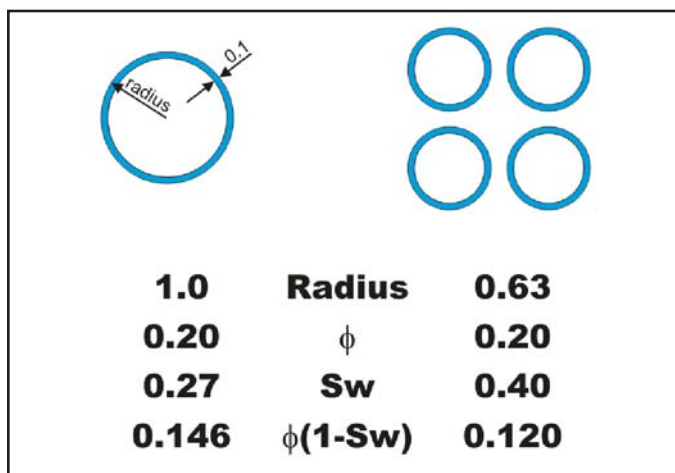


Figure #5: Relating Pore Size to Porosity & Water Saturation

Considering the Data

Theory will only take us so far, and then we need to look at real data. For this we have combined two special core analysis reports into one data set. The first special core analysis is from the east coast of Canada, and the other from Africa. Both were from shaly sands. Figure #6 presents this data on a typical porosity versus permeability cross-plot.

The hazards of using a porosity/permeability relationship are very clear here. A "Best Fit" through this data might suggest the permeability at 22 percent porosity should be 30md. But the data shows a range of permeabilities at that porosity from 3 to 300md. The range of error is too great for this relationship to be acceptable.

Applying what we have observed regarding relative pore size, we find that the data trend (Figure #7) becomes much narrower. It would be rather simple to determine a polynomial or power relationship for this data ... but which one best represents the data? In seeking an answer to this, we discovered a log10 function of the x axis left us with a linear data trend. (See Figure #8)

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Permeability from Open-Hole Logs ... continued from page 32

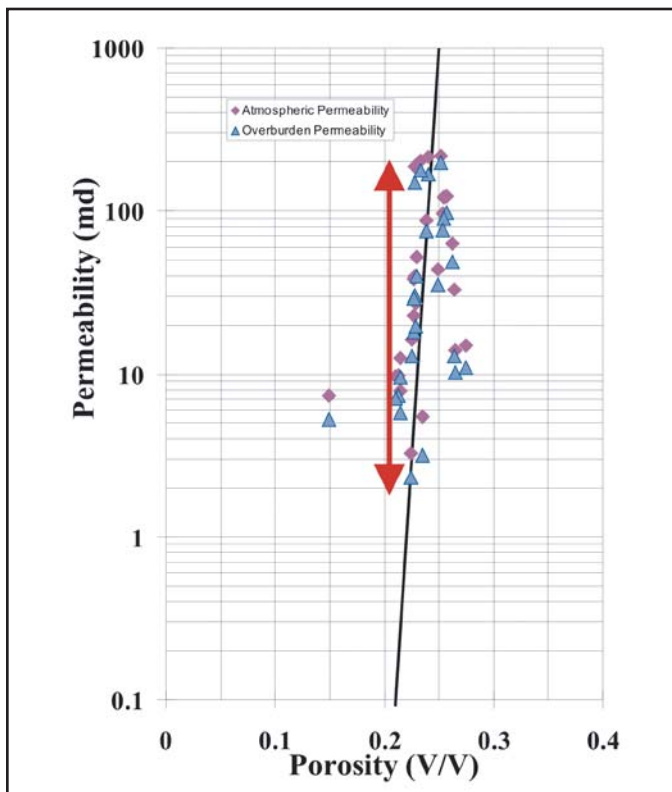


Figure #6: Typical Porosity/Permeability Presentation

A linear trend is much easier to represent in an equation, and the range of error in permeability is consistent at all porosity values. Here we fit the overburden permeability data to arrive at the following relationship:

$$\log K = 3.9 \times \log(\phi(1 - S_{wi})) + 5.0$$

where: K is the permeability,
 ϕ the effective (non-shale) porosity,
 S_{wi} is the irreducible water saturation.

Simplifying this equation we can write:

$$K = 100000 \times (\phi(1 - S_{wi}))^{3.9}$$

We now have permeability as a function of porosity and water saturation. This relationship is based upon the assumption porosity and irreducible water saturation combined give us the relative pore size, and therefore an indication of the average pore throat size. Since permeability is a function of area

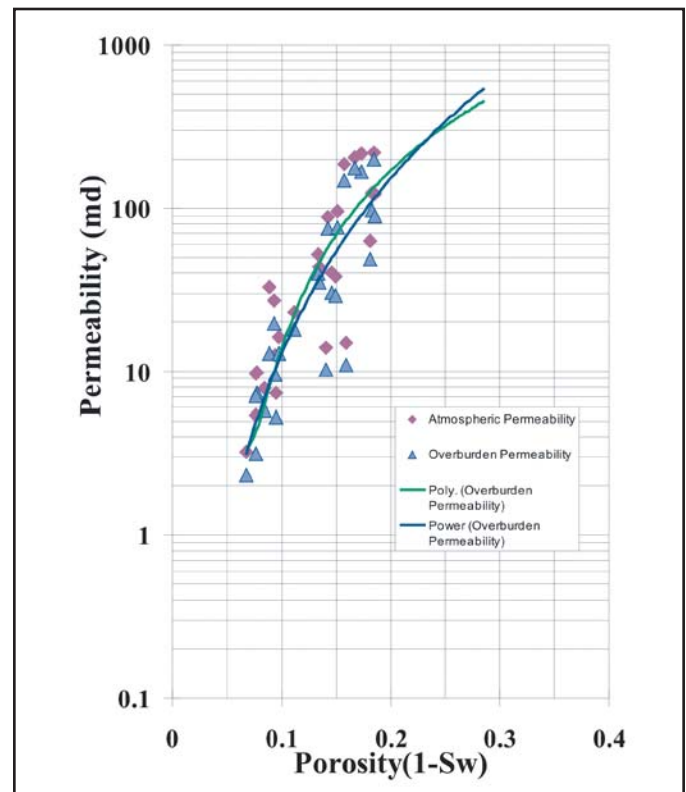


Figure #7: Relating Relative Pore Size (the product of Porosity and $(1 - S_{wi})$) to Permeability

through which fluids must flow, we can reasonable expect this relationship to apply in any intergranular or intercrystalline reservoir.

A simple graph representing this permeability relationship in terms of porosity and water saturation is shown in Figure #9. By entering the x axis with the effective (non-shale) porosity¹, and the y axis with the water saturation, the reader is able to predict the range of permeability to expect.

From this cross-plot we can identify the expected permeability given porosity and water saturation. Thinking back to Darcy's original work we see that with constant pressure and fluid properties, the maximum flow rate is defined by the cross-sectional area of the tube. It should not surprise us then to find there is a maximum permeability for any given porosity. That maximum is reached when water saturation approaches zero.

¹ Effective Porosity is defined in petrophysics as the volume of pore space available to contain both hydrocarbons and formation water, but excluding any water associated with clay. Likewise we define Total Porosity as the total pore volume, including the water associated with clay. The raw porosity log is a measure of Total Porosity. In clean carbonates total and effective porosity are the same, but not in shaly sands.

Permeability from Open-Hole Logs ... continued from page 33

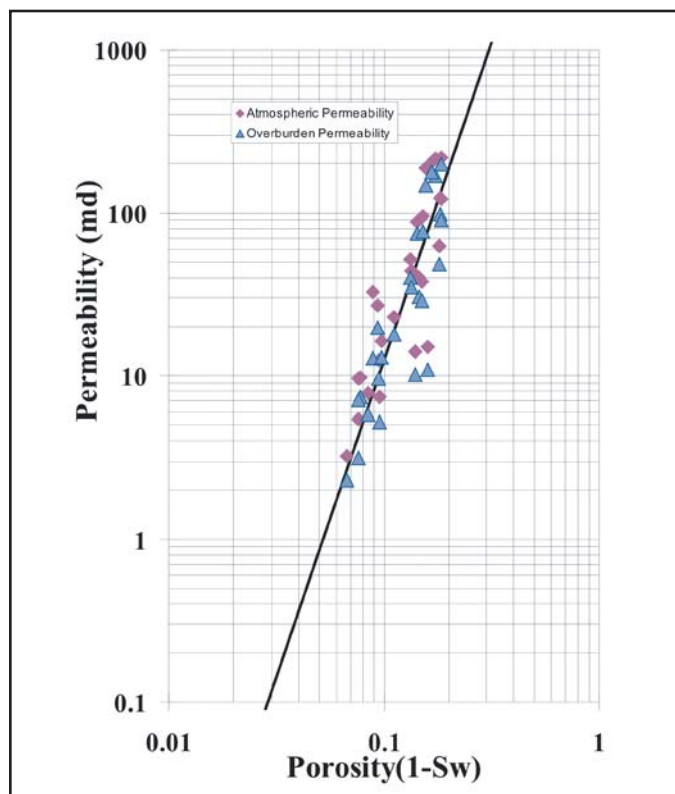


Figure #8: Logarithmic Presentation of Data

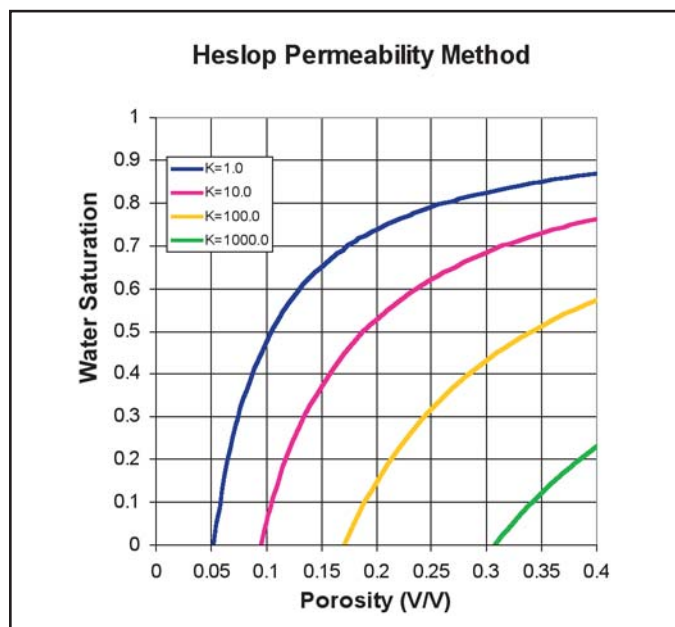


Figure #9: Heslop Permeability Relationship

Permeability equations are generally based upon two assumptions: the first that an intergranular or intercrystalline pore system exists; the second that the formation is at irreducible water saturation. With the exception of production due to fractures, it is reasonable to assume the intergranular or intercrystalline pore system controls permeability in most shaly sand and carbonate formations. In certain cases the vugs in carbonates will have a greater influence than the intercrystalline pores, and this relationship will no longer apply. When dealing with carbonates in general, water saturations should be corrected through the use of a variable cementation exponent “m” to correct the resistivity for the effects of vugs, or other such pore types.

Real-Life Examples

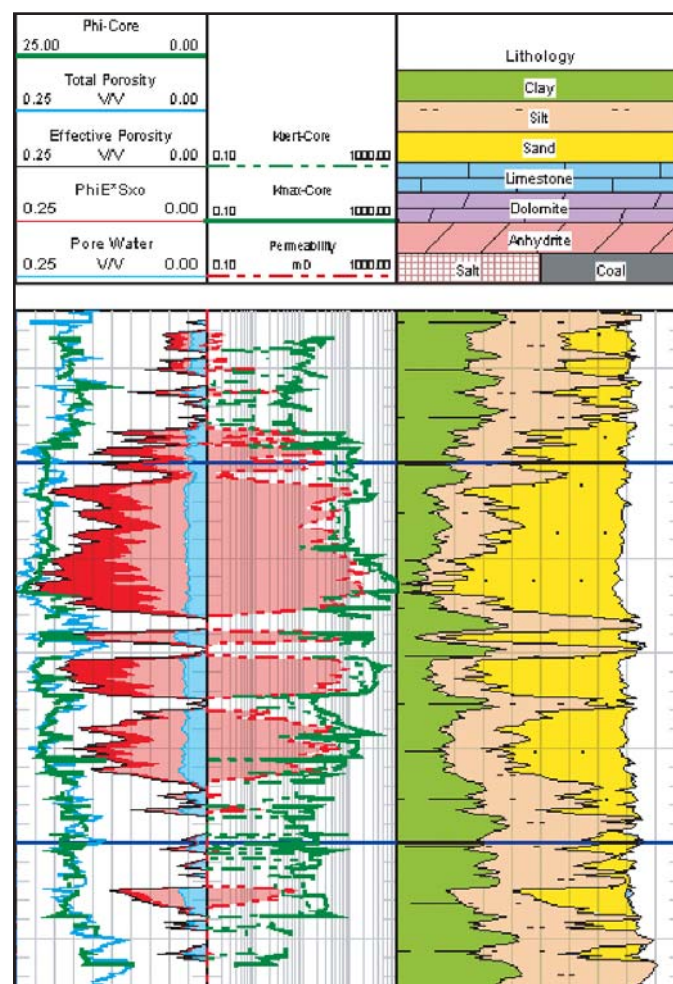


Figure #10: IOL Taglu G-33

In this example from the Northwest Territories, we see how core porosity and total porosity track. This is because the he-

Permeability from Open-Hole Logs ... continued from page 34

lium used to measure porosity can even penetrate into the clays. The effective porosity only approaches core porosity in the cleanest sands. As a result, permeability measured in the core for these shaly sands tends to be slightly higher than we predicted from logs. (In this core analysis even the shale has permeability reported!)

Our second example comes from a well in the east of Africa.

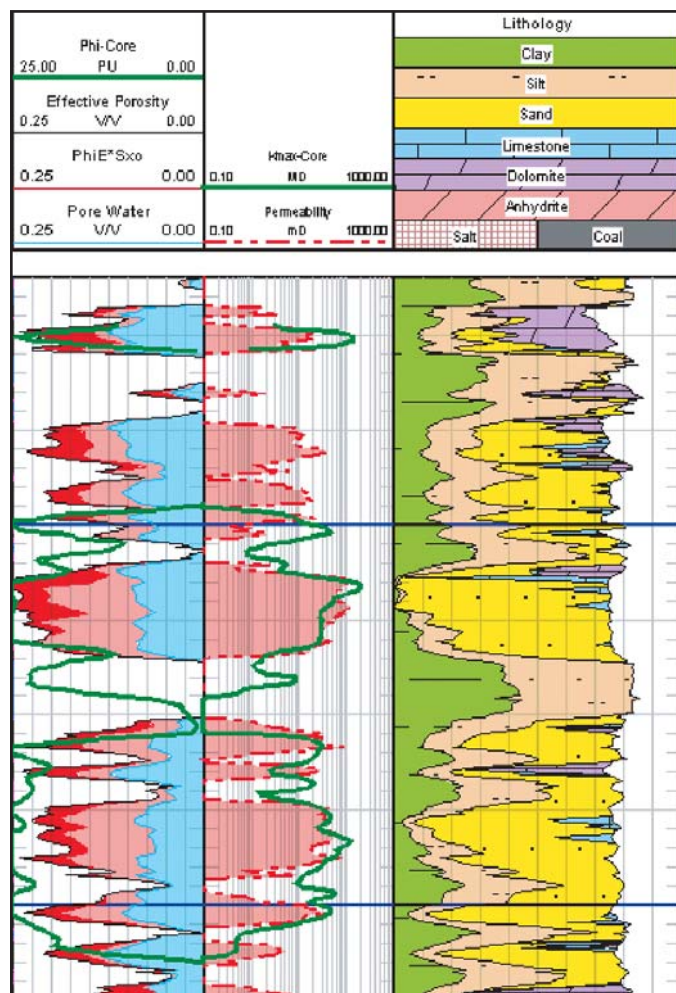


Figure #11: An Example Out of Africa

This is a short interval from a very extensive section of log and core data. Once again we observe that core porosity is equal to total porosity, while effective porosity in the clean sands approaches core porosity. Notice here how closely the log permeabilities match the Kmax. We did not have Kvertical from this core. But Kvertical and Kmax are often very close in sands.

Our last example comes from the Golden Spike field. This limestone reef was extensively cored, but here we show just the top 70m of the reef.

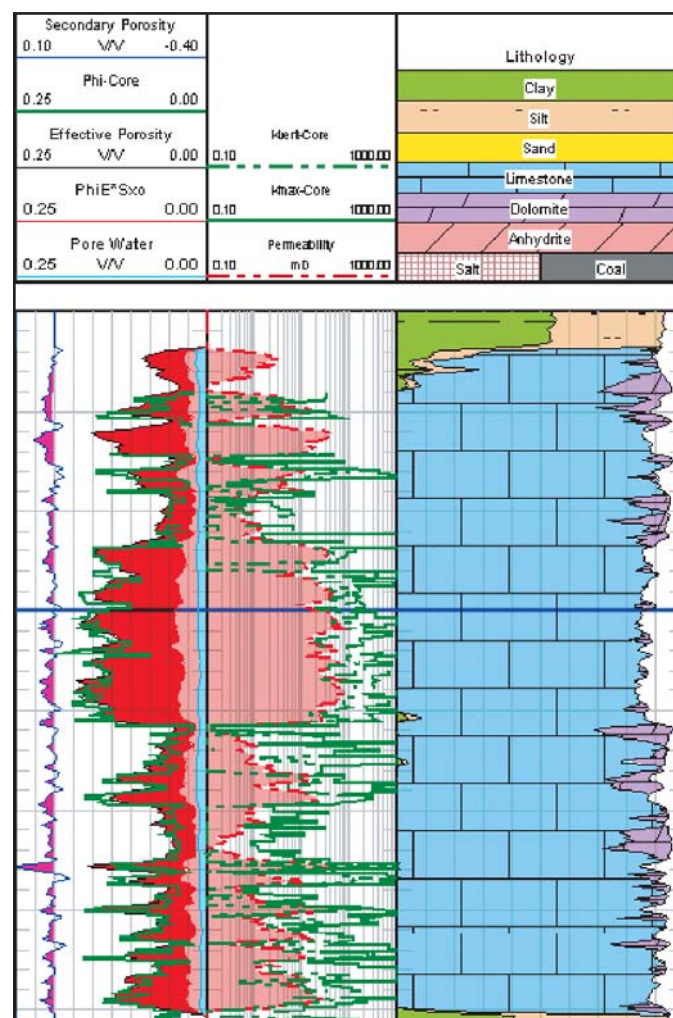


Figure #12: Golden Spike 15-23-051-27W4

In this limestone reef we observe how well the log porosity matches the core porosity. But when we compare the permeabilities, it becomes clear the Kmax data are slightly higher than the log permeabilities. Kvertical, however, matches the log permeabilities very well.

Permeability from Open-Hole Logs ... continued from page 35

Review of Other Methods

This is not the first method proposed to calculate permeability from porosity and water saturation. Two permeability relationships that often appear in the literature are those proposed by Timur and Coates respectively. Each of these deserves evaluation.

The Timur relationship was given as:

$$K = \left[\frac{100 \times \phi^{2.25}}{S_{wi}} \right]^{2.0}$$

When plotted in terms of porosity versus water saturation, this relationship takes the form shown in Figure #13 below.

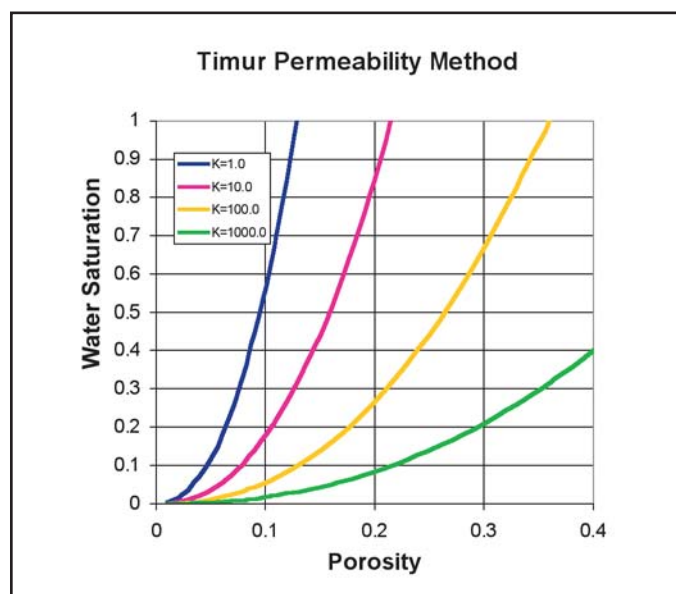


Figure #13: Timur Permeability Relationship

Similarly the Coates permeability relationship was given as:

$$K = \left[\frac{70 \times \phi^{2.0} \times (1.0 - S_{wi})}{S_{wi}} \right]^{2.0}$$

This relationship was likewise plotted in terms of porosity and water saturation in Figure 14.

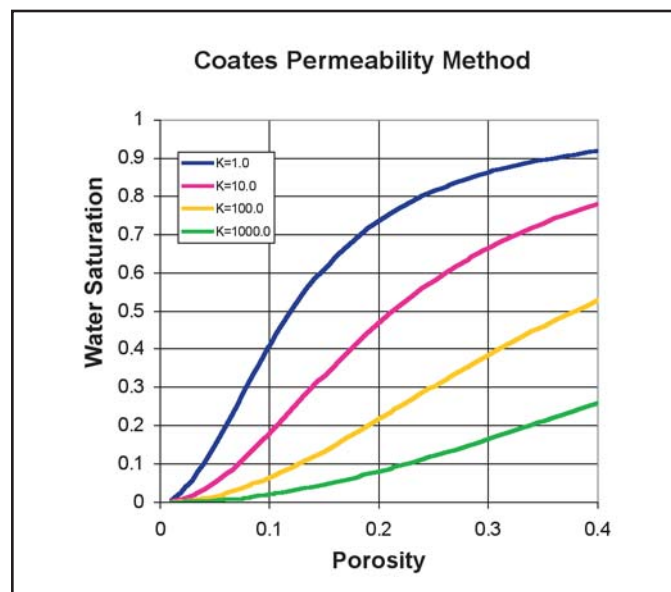


Figure #14: Coates Permeability Relationship

Thoughtful examination will note both of these permeability relationships suggest a formation with very low porosity can have very high permeability (in the range of 1000md or more,) and in particular when the water saturation is less than 5 percent. If we removed all formation fluids, permeability should be directly related to the average pore throat diameter and the number of pore throats available for fluid flow. (The presence of formation water has the effect of reducing the effective pore throat diameter, and therefore the permeability.) When the effective porosity is low there will be fewer pore throats available for fluid flow. It then follows that there is a maximum permeability associated with any effective porosity when water saturation approaches zero. Since we seldom find irreducible water saturations less than 5 percent when effective porosity is less than 5 percent, this inconsistency noted in these relationships is not of practical significance.

Of greater significance is the assumption in the Timur relationship that high permeability can exist in formations with high irreducible water saturations. In Figure 13 above it is evident this relationship would result in 100 md of permeability in reservoir rock with 30 percent porosity, and 67 percent irreducible water saturation. Experience has shown these porosity and saturation conditions are representative of a chalky limestone. Chalk is seldom considered a highly permeable formation.



Permeability from Open-Hole Logs

... continued from page 36

Above 30 percent irreducible water saturation the Coates and Heslop relationships are in close agreement. The window of agreement between the Timur relationship and the other two is very small. In general, use of the Timur relationship results in higher permeabilities than would be obtained from either of the other two.

Conclusions

Accepting the assumption of an intergranular or intercrystalline pore system, and that the formation is at irreducible water saturation, it is possible to obtain meaningful permeability data from well logs. The permeability equation developed in this paper has been tested and compared to core permeability data in both shaly sand and carbonate reservoirs in many areas of the world. It has consistently provided reliable results.

We know permeability in fractured rock will be much higher for any given porosity, because fluid flow is not restricted by the pore throats. At the same time we know core porosity data in very shaly sands and siltstones are not representative of the effective porosity. Permeability data obtained from these cores tends to be optimistic.

While acknowledging the limited data set used in developing this relationship ... this data did not include low porosity and permeability data ... our experience has shown this relationship works across the entire spectrum of porosity and permeability data. The data set used here exhibited good linear behavior in a tight trend. It is then reasonable to extrapolate this data to predict permeability in lower porosity clean rocks, where the pore systems are similar to these intergranular rocks. Experience has confirmed this confidence.

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UNDERSTANDING WELL LOGS

May 28

Calgary Petroleum Club, lunch included. This one day seminar is designed for Land, IT and non technical support staff who wish to have a qualitative understanding of well logs. Math content is minimal and no prior well log experience is needed. Candidates will learn to recognize obvious zones of interest and understand the importance of the basic log curves.

Fee is \$400 + GST

BASIC WELL LOG SEMINAR

January 3-5, May 23-25, October 3-5

Calgary Petroleum Club. This popular seminar is intended as a refresher course and is also suitable for recently graduated geologists, engineers and technicians with some knowledge of well logs. A complete discussion of the qualitative and quantitative applications and the newest logs.

Fee \$1175+GST

INTERMEDIATE WELL LOG SEMINAR

Jan.10-12, May 30-June 1, Oct. 10-12

Calgary Petroleum Club. This seminar provides an in depth look at the relationships for well log analysis and includes a reconnaissance method for finding by passed zones, a module on shaly sand analysis, responses from the newest logs, through casing gas detection, and a section on Coal Bed Methane logging. CD provided with reservoir log plots for 79 reservoirs. Designed for candidates who have used logs qualitatively and wish a refresher and update on quantitative applications.

Fee \$1350+GST



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.

FEES

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 MasterCard, AMEX 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.

APPLICATION

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

CWLS MEMBERSHIP APPLICATION FORM

To apply for membership to the CWLS, please complete this application form in detail.

NAME:.....

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ADDRESS:.....

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ADDRESS:.....

E-MAIL ADDRESS:.....

PREFERRED MAILING ADDRESS:

E-MAIL _____ OFFICE _____ HOME _____

BUSINESS
PHONE:.....

RESIDENCE
PHONE:.....

PROFESSIONAL
DISCIPLINE:.....

SIGNATURE:.....

DATE:....., 20

CWLS SPONSORS: (Members in good standing)

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FEES

Please enclose initiation fees (Cheque, money order, MasterCard, AMEX or Visa) with the application of membership and mail to:

**Membership Chairman
The Canadian Well Logging Society
2200, 700 – 2nd Street S.W.
Calgary, Alberta T2P 2W1
Canada**

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Wednesday, September 20th, 2006

CWLS TECHNICAL LUNCHEON PRESENTATION

FAIRMONT PALLISER HOTEL

133, 9TH AVE. S.W. CALGARY

TIME: 12:00 PM (COCKTAILS AT 11:30 AM)

RESERVATIONS BY: Friday Sept 15th, 2006 (NOON) - CALL 269-9366 TO CONFIRM A SEAT

COST:

MEMBERS RESERVED MEAL: \$30.00; NON-MEMBERS RESERVED MEAL: \$35.00
(SPECIAL NEEDS MEALS AVAILABLE WITH ADVANCED BOOKING ONLY)

TOPIC:

NEXEN'S YEMEN BASEMENT POROSITY MODEL

SPEAKER:

**David Thurston and Doug Bearinger,
Nexen Petroleum International**

ABSTRACT:

Yemen's Sunah Basement Oil is produced from fractured and faulted crystalline rocks overlain by Jurassic and Cretaceous sedimentary rocks. Precambrian metamorphic gneisses were intruded by granitic magmas in the late Precambrian. Jurassic rifting resulted in tilted block faulting with Basement juxtaposed against sedimentary rocks. To evaluate porosity in this unconventional reservoir both image logs and a conventional log suite were used. Image logs were used to calculate fracture porosity from fracture intensity. Because of the variable mineral nature of metamorphic and igneous rocks, a multimineral model was used to calculate porosity from the conventional log suite. Gas log ratio analysis and oil staining was used to determine pay intervals. A geocellular model was constructed by mimicking the architecture and history of porosity development. The input of two porosities along with fault and contact objects allowed the building of a complex porosity model.

BIOGRAPHY:

Doug Bearinger is a Geology Advisor with Nexen Petroleum International Ltd. and is based in Calgary, Alberta, Canada. His principle focus is the development of a fractured basement reservoir within the Yemen Masila Block. Prior to 2000 he explored for and developed oil and gas reservoirs in Western Canada. From 1982 to 1994, he worked as an exploration geologist for Home Oil Co. Ltd. in various plays in Canada. He graduated in 1982 with a BSc in Applied Earth Science-Geotechnical Option from the University of Waterloo, Ontario, Canada.

David Thurston is a Senior Petrophysicist with Nexen Petroleum International Ltd. Based in Calgary, Alberta, Canada. Currently working with the Long Lake Synthetic Oil group, David has spent the last five years providing Petrophysical support to Nexens' Yemen groups as well as other international operations. Prior to 2001 David worked as a wireline engineer for Computalog Ltd throughout the Western Canada and Mexico. He graduated in 1991 with a BSc in Applied Earth Sciences from the University of Waterloo, Ontario, Canada.

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

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Thursday, October 12th, 2006 CWLS TECHNICAL COURSE ENGINEERED AIR THEATRE EPCOR CENTER for the Performing Arts 205, 8TH AVE. S.E. CALGARY

TIME: 7:30 AM – 4:30 PM

MEALS: BREAKFAST, LUNCH, SNACKS INCLUDED

**RESERVATIONS BY: Monday Oct 9th, 2006 (NOON) OR UNTIL SPACES ARE FILLED
CALL 269-9366 TO CONFIRM A SEAT**

COST: MEMBERS: \$100.00; NON-MEMBERS: \$200.00
To become a CWLS member go to:
https://cwls.org/private/membership/application_form.php

COURSE TOPIC: CWLS NMR COURSE

SPEAKER: Brian Stambaugh, President of NMR Petrophysics, Inc

ABSTRACT:

This course is a presentation of middle to advanced level topics with respect to Nuclear Magnetic Resonance (NMR) Logging. Many examples are used representing a variety of formations and evaluation issues, with many from Canada, and with a focus on tight gas and viscous oil. Attendees are invited to bring their own log examples and experiences for discussion.

BIOGRAPHY:

Since 1997, Brian Stambaugh has been president of NMR Petrophysics, Inc., a petrophysical consulting firm in Houston, Texas. Previously Brian was with Schlumberger as a field Engineer, and Numar where he assisted in operations, processing, and interpretation efforts as NMR technology emerged. His experience with NMR has included data sets from over 1500 wells. He has given short courses to more than 650 students on NMR operations, interpretation, and data processing and provides technical assistance for oil companies and for oil service companies. He has served as an SPWLA Distinguished Lecturer and SPE Technology Transfer Speaker. Brian holds a B. S. M. E. from South Dakota School of Mines and Technology.

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



Voting is cool!

Safety tip: Don't drink and vote.



The Canadian Well Logging Society General Election

Ballots Mailed to All Members the First Week of January



UPCOMING EVENTS

September 20, 2006

CWLS Technical Luncheon

Speaker: David Thurston and Doug Bearinger,
Nexen Petroleum International
Fairmont Palliser Hotel, Calgary, AB

October 4-5, 2006

12th Annual Formation Evaluation Symposium of Japan

JOGMEC-TEC, Chiba, Japan

October 12, 2006

CWLS Technical Luncheon

Speaker: Brian Stambaugh,
President of NMR Petrophysics, Inc
EPCOR Centre for the Performing Arts, Calgary, AB

October 29 - November 2, 2006

Petrophysics under Stress ñ A Joint SPWLA/CWLS Conference

Delta Lodge at Kananaskis, Alberta Canada

November 5 & 6, 2006

Perth 2006 AAPG International Conference

Perth Convention & Exhibition Centre
Perth, Australia

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- 2) Wellbore Data Acquisition and Uncertainty and
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Ben Urlwin (ben@waveformenergy.com)
at (403) 538-2185

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at (403) 260-6248

**Discounts on business card advertisement
for members.**

A high resolution .pdf of the latest InSite
is posted on the CWLS website at
www.cwls.org. For this and other
information about the CWLS visit the
website on a regular basis.



*Sunrise across the Yemen landscape near the Nexen CPF.
Photo courtesy of Carole Augereau*



*Heli leaving Shearwater – Offshore North Sea.
Photo courtesy of John Hull*



*Shearwater Platform – Offshore North Sea.
Photo courtesy of John Hull*

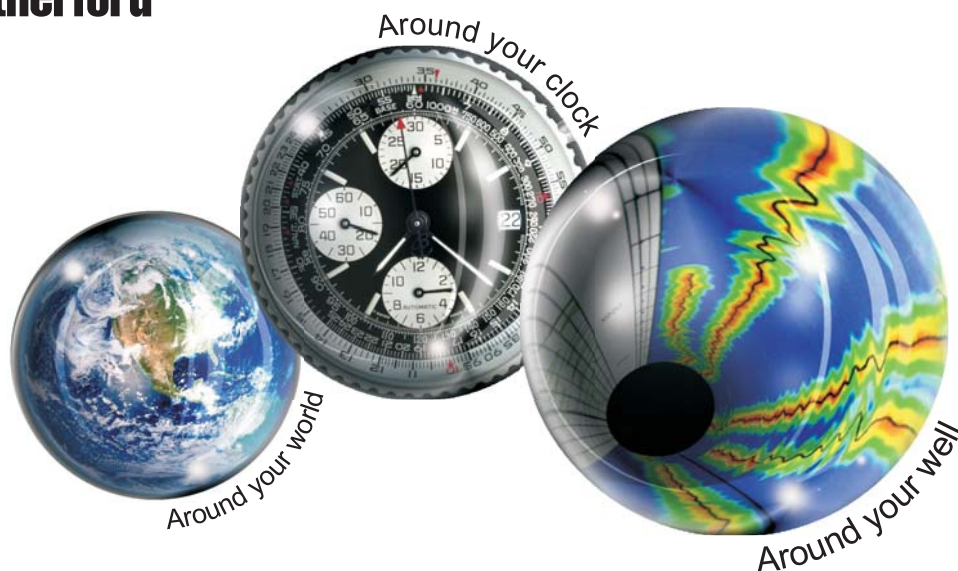


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