InSite

CWLS Magazine
June 2007 Issue 2 Volume 26

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InSite

CWLS Magazine **June 2007**

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Valle de Luna, Chile - Gypsum, Sandstone deposits
Photo courtesy of Jolane Sorge

If you have a photo that the CWLS can use on its next InSite cover please send a high resolution jpeg format version to Tyler.A.Maksymchuk@conocophillips.com or Kelly.S.Skuce@conocophillips.com. Include a short description of the photo with your submission.

The 2007 - 2008 CWLS Executive:

Front row (l - r): Greg Schlachter, Cindy Guan, Jeff Taylor, Kelly Skuce.
Back row (l - r): Roy Benteau, Peter Kubica, Vern Mathison, Tyler Maksymchuk, Gordon Uswak.

President's Message

Your Pipeline to the Top

Instead of my usual tirades championing training, mentoring and preparing ourselves and our industry for the upcoming shortage of skilled workers, in this issue I need to pause and take a moment to provide an update of the secretive goings on at the lofty heights of CWLS headquarters.

Today, the main priorities of the CWLS are to:

1. Add value for the FE community. Such as data submission standards and dealing with provincial governments, maintaining core and Rw databases, publishing the InSite magazine, actively participating and helping organize the many industry conventions.
2. Add value for our members. Such as the technical lunches, sponsors training and courses, providing a forum for job seekers and employers (and all these events are really great for networking), and of course the AGM.
3. And, be actively involved in planning for the future of our profession. It is not difficult to see that the average age of our members is getting up there and with the downturn of 1986-1999, not many people entered the oil business. So we are actively involved with the universities and technical colleges in Western Canada. That means being involved with Student Liason Committees, scholarships and awards, discounted Student memberships, participating at open houses, and so on.

So for this issue, I hope to give you an update on what we are doing about these priorities.

The Canadian Well Logging Society announces yearly awards for engineering and earth sciences undergraduate and graduate students in Canada. Last month it was a real pleasure to present a $5000 award to Yanping Niu whose University of Calgary graduate thesis was excellent. Her thesis was entitled, *"Determining the Content of Bitumen, Water and Solids in Oil Sands Ore using Low-field Nuclear Magnetic Resonance"*. For more information, see the CWLS.org website.

The CWLS has also recently partnered with the University of Calgary Petroleum Club. This means the 100-150 or so Engineering, Geology and Geophysics students who join this club every year will automatically be given a Student membership to the CWLS. We will also provide speakers for their monthly meetings as well as provide some financial support for the Club's industry field trips.

We are also increasing the manpower in our Student Liason Committee. So, you may get a call from Louis Chabot or one of the execs to volunteer (call Greg Schlachter, CWLS Chair of Committees).

For our members and the FE community, we have agreed to participate annually in the Geo-Triad (CWLS/CSPG/CSEG) conferences. In the past, we have only participated every 2 years. Again, you may get a call from one of the execs as we will need a volunteer to act as a liason with the other societies to help plan future conferences. For the 2008 conference, Brian Glover is the CWLS coordinator and will be looking for volunteers, technical session chairs, etc. (Again, if you can volunteer, contact Greg Schlachter)

For those who attended the May luncheon, you may have noticed the 2 screen setup in the Crystal Ballroom. We are seeing an increasing attendance at our luncheons and there are fewer venues. Instead of limiting ticket sales, Roy Benteau (CWLS VP) is coordinating with the Palliser to ensure that we will have access to their Crystal Ballroom for future luncheons. Hopefully the dual screens and larger room is a better setup.

Our website will continue to evolve and become more functional. The changes cause problems from time to time and we have just purchased a new server and have arranged for the software to be cleaned up and to be managed by a different firm.

For now, the CWLS will continue along this path:

- to continue to add value for our membership and the FE community
- to strengthen our involvement with the students and their schools to help guide those considering our profession and attract more students to FE

Have a great summer and see you in the fall.

Jeff Taylor, P.Eng.
CWLS President

Editor's Note

Welcome to the June edition of the CWLS InSite. This time of the year everyone's thoughts start to turn to holidays, conventions and conferences and it looked like the past CSPG/CSEG convention here in Calgary went well. Even if I didn't win the silent auction stuff I bid on, it was good to see some familiar faces from around town at the CWLS booth. Let's all try to make the 2008 CSPG/CWLS/CSEG convention as great or better the convention in 2006. The SPWLA conference in Austin is also fast approaching at the beginning of June and I hope to see some of you down there as well.

We have quite the issue this quarter with one local paper from Barry Johnson and Harold Hovdebo of Husky Energy on "Acquiring Density Data in Elongated, Directional Boreholes Drilled Through Stressed Formations of Western Canada and an out of country paper originally presented at the SPWLA Middle East Regional Symposium last month titled "Low Permeability Gas Reservoirs: How Low Can You Go?" jointly published by the SPWLA and Mike Miller, Bob Lieber, Gene Piekenbrock and Thal McGinness of BP America. The Tech Corner presentation is a repeat of the slides from the May 8th CWLS luncheon "An Alternate Approach to find the Volume of Shale" from Bob Everett et al if you missed it. As always we have a great story in "As the Winch Turns" about how far practical jokes used to go in the field and you better be able to eat what you dished out!

Enjoy this quarter's issue and I hope everyone has a great summer and remember to attend the June 7th CWLS Luncheon on Geomechanical Wellbore Imaging from Colleen Barton of GeoMechanics International Inc. This will be the last luncheon before the summer break and then you will hear from us again in September.

Have a great summer.

Publishing Co-Editor
Kelly Skuce

Bob Everett - May 2007 CWLS Speaker
Photo courtesty of Peter Kubica

Yanping Niu - 2006 Recipient of CWLS Master's Thesis Award
Photo courtesy of Peter Kubica

As the Winch Turns

When I look at the new oil patch and actually take the time to think about it I suspect the most striking change is the change. Every year brings new methods and equipment. On the first job I ever sat, an assistant driller, fueled by Scotch had said that it was too bad we could not drill sideways. His audience, also containing a lot of my Scotch had laughed themselves silly. Now it is hardly worth mentioning when a lateral leg is over 2000 meters long.

But the biggest change I can find is the absolute lack of practical jokes. When I started there were people that seemed to view the drilling of an oil well not as a search for black gold but rather as a fertile field for their jokes. Most of them were one off repeats of past tricks and a few were winter long set ups that left all of us in awe. Usually the jokes were pulled on some poor unsuspecting mark, but on occasion they were pay back.

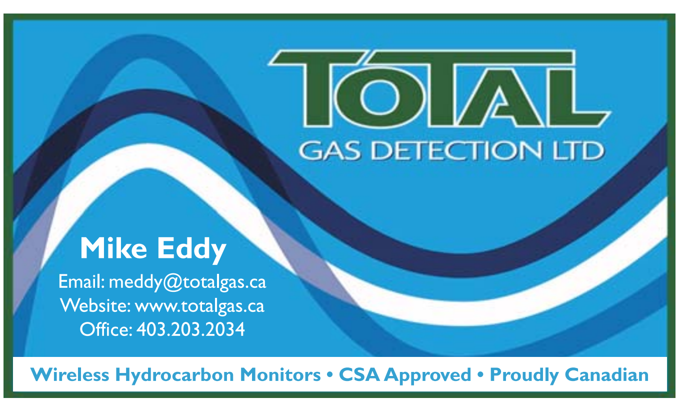
The most vicious protracted war that I every witnessed happened up the Beaton River Road in the early nineties I am not sure what started the original fight but when I became aware of the war Freddie the Band Aid was said to have called the Second Cook a “man in a women’s body”. She was not amused in the least and let it be known that no prisoners would be taken.

The opening volley was predictable. Freddie left lunch one afternoon and found raw eggs in his boots and parka pockets. An oldie but a goodie. A few days later he reported that his bed had been filled with Corn Flakes. The next move did not require any public announcement. It would have been difficult to hide. She had filled his pillow with garlic powder. After a good nights sleep Freddie had no reason to fear vampires. He reeked for days. He was starting to look a bit down in the mouth, while the Second Cook was becoming perkier by the day.

The next one took the whole night crew. They made up the most beautiful head stone out of a piece of board and fastened it to his shack. Freddie was starting to complain about feeling picked on. There were other pranks, but they have faded with the passing time. The one that broke him was pure evil genius. She waited for that first warm spring day when all the snow started to melt, especially on shack roofs. While Freddie was eating supper she went out and threw a bunch of bacon up on his roof. The next morning the boys coming up from the rig counted 41 ravens trying to peck the bacon out of the now frozen snow.

At lunch Freddie came into the dining room, got down on his knees in front of the Second Cook and begged forgiveness.

Dave



Message from the Vice President

Wow, it is almost summer break and the last six months have seemed to disappear without a trace. It feels like only days ago that I was putting on the winter clothes and running out to my favorite cross-country ski spot for an afternoon of slipping, sliding and enjoying the crisp cold air. Sitting on my back deck today in the heat of the sun watching the robins and sparrows scurry around I had to force myself to go back over the events of past months. I found this exercise to be so rewarding that I wrote this message outlining my memory of luncheon talks so far this year.

Basim Faraj, PhD of Talisman Energy Inc. started the 2007 luncheon program on January 10th with a talk on "Shale Gas". Basim is a practiced presenter and convention chairman and gave an excellent talk outlining the geologic and geochemical attributes of the Woodford Shale, focusing on completion practices. Though explorers have known there was gas in shale, the host rock's permeability (micro to nanodarcy) is so small that it will not move freely into the wellbore without creating pathways. A combination of slickwater stimulation technology and microseismic monitoring illustrated how Talisman was able to respond to the unpredictable nature of shale gas and maximize benefits. Although I have attended many talks of this type, this was the first time a presenter discussed the specific design of their slick water stimulation.

On March 7, 2007 Milovan Fustic, P.Geol. now with Nexen Inc. gave a talk on "Dipmeter Applications in Oil Sands". Milovan's goal was to show the evolution of dipmeter applications, demonstrate the advantages and simplicity of the tool and highlight that the dipmeter is underutilized and he did so with flair and great illustration. I was impressed at how his approach allowed him to identify individual channel trends, and model the complex geometry and internal architecture of point bars, abandoned channels and tidal flats to pick the "sweet" spots with sparse drilling data. Although I am not involved in the Oil Sands or Heavy Oil, his talk intrigued me enough to do additional reading on the subject and I believe I now have some better tools for predicting reservoir geometries in my exploration areas.

Lunch on April 11, 2007, Salman Khalid, ID Petrophysics DCS-CAN Schlumberger gave a presentation on "Shale Gas Log Analysis". The talk outlined the various techniques being applied to Canadian shale, grouping the techniques into exploration and exploitation. The exploration techniques recognize the reality that historical databases do not contain specialty log data so cutoffs on individual curves (gamma ray, SP, resisitivity), neutron density separation, and Delta Log R (sonic resisitivity overlay) need to be used to calibrate logs to core and infer gas in place. During the initial exploitation stages it is important to understand heterogeneities in the shale, mechanical properties, fracture, stress regimes, etc. to properly design drilling and stimulation programs. Using a released Canadian example Salman showed how logging measurements including NMR, Dipole Sonic, Elemental Capture Spectroscopy and micro-resisitivity imaging helps operators take advantage of natural rock weaknesses.

Bob Everett, BASc, Petrophysical Consultant with over 41 years of experience forced us back into thinking about Vshale in a conventional way with his luncheon talk titled: "An Alternative Approach to Find VSHALE - Handling the Influence of Clay Minerals on Estimates of Porosity and Permeability". After I got past an uneasiness to creating log curves when data is sparse I could see the value of his well thought out systematic approach to handling mineral components, irreducible porosity, total clays and free fluids. His example which looked very familiar, his willingness to provide all the details of his methodology and his absolute belief in this approach has convinced me to investigate it further and read the Heron paper (SPE 77631). I commend Bob for thinking "Outside the Box" to describe our "Box of Rocks".

The last luncheon talk of the season on June 7th, 2007 will feature a presentation by Colleen Barton, PhD, Senior Technical Advisor, Co-Founder of GeoMechanics International Inc. titled: "Geomechanical Wellbore Imaging: Key to Managing the asset Life Cycle". I know this talk will be stimulating and provide a road to understanding permeability and how to increase the economic lifetime of our mature reservoirs. I hope to see you all at this luncheon but in case I do not, I hope you have an enjoyable and happy summer. Don't forget to sit back and take time to think about the great things that have occurred in your life.

Cheers, Roy Benteau
CWLS Vice President

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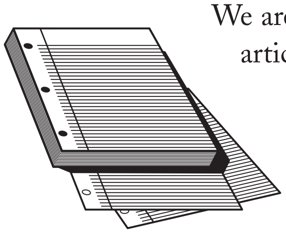
Call for Papers



The CWLS is always seeking materials for publication. We are seeking both full papers and short articles for the InSite Magazine. Please share your knowledge and observations with the rest of the membership/petrophysical community. Contact publications co-chairs Tyler Maksymchuk (Tyler.A.Maksymchuk@conocophillips.com) at (403) 260-6248 or Kelly Skuce (Kelly.S.Skuce@conocophillips.com) at (403) 260-1931

Acquiring Density Data in Elongated, Directional Boreholes Drilled Through Stressed Formations of Western Canada

By Barry L. Johnson and H.S. Hovdebo

Abstract

Wells drilled in the WCSB, and particularly in the Alberta foothills, are influenced by the regional stress regime. In general, the axis of minimum principal stress is oriented in a NW-SE direction, precipitating borehole breakout along this trend. The result is elongated (elliptical) wellbores that are frequently rugose along the axis of elongation. Density tools invariably incorporate a back-up caliper to maximize pad contact with the borehole wall. Poor density data is often acquired, as the design tends to "lock" the measurement section of the tools into the rough side of the hole. Technology to aid in the acquisition of density information in elliptical wells has improved over the years with the introduction of various running gear and tool configurations (e.g. "90-degree calipers", "90-degree hardware" and, more recently, "dual-densities"). Density data thus acquired has improved, but deviated wellbores can render standard tactics ineffective.

This paper addresses the acquisition of wireline density data in the Deep Basin area of Alberta. Specifically, existing logging tools were configured in such a manner as to maximize pad contact and increase the probability of acquiring high quality density data in orthogonal axes of the wellbore. Assuming some sector of the wellbore is not affected by breakout, the technique affords more reliable density measurement in deviated wellbores. Additionally, the data presented herein confirm, that wellbore breakout is oriented in a NW-SE direction in the area of investigation.

The primary purpose is to convey to the CWLS membership some lessons learned in trying to make valid density readings in low to moderately deviated wells, even when drilled along strike (into the "breakout" or minimum principal stress direction). It is hoped that further interest is generated, leading to advancements that will improve density acquisition in other hole sizes and/or at higher inclinations.

Introduction

Acquisition of valid bulk density log data in the foothills area of Alberta has been a recognized challenge since the introduction of gamma-gamma density logging technology in the 1960s. Over the years, various technological advances have limited the extent of the problem, but under certain circumstances it is still difficult (or impossible) to get a good bulk density log. For the most part, innovations have focused on trying to turn the toolstring in the hole so that the density skid consistently faces the short (and presumably smooth) axis of the hole.

A number of exploration and production companies active in Western Canada have made it a standard practice to run so-called "dual density" or "tandem density" tool configurations in the Foothills and Deep Basin areas. The intent is to increase the probability of acquiring valid density data. Overall, the strategy has worked. Recently, however, the number of wells drilled directionally has risen. The prevailing practice in deviated wellbores is to avoid running dual-density toolstrings or to close one tool if inclination appears to be interfering with data acquisition. Sometimes the data is just accepted "as is". However, even at moderate inclinations, a significant increase in the incidence of density acquisition problems is observed. It is clear that improvement is needed with respect to bulk density logging in directional wellbores.

Identification of the Problem

After logging over 100 wells in the Ansell-Galloway area, many of them directionally, some degree of insight has been gained into the nature of logging tool behaviour. Figure 1 is a schematic of a typical dual-density toolstring in a vertical well-

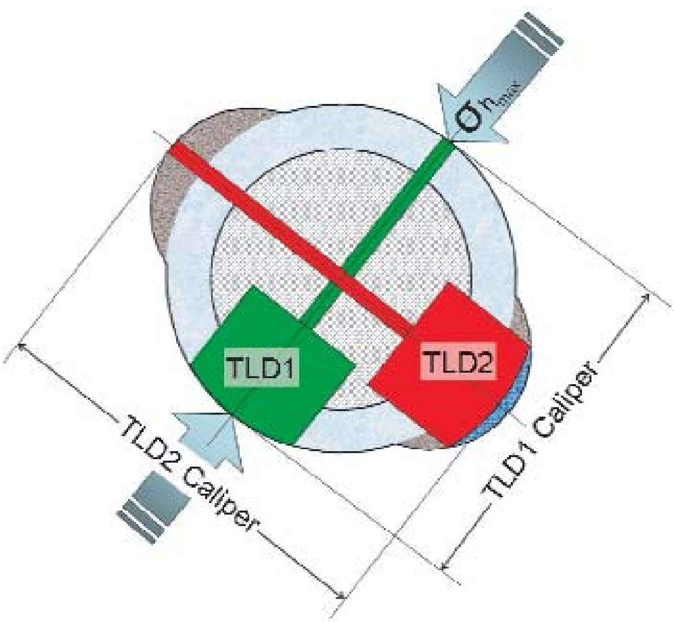


Figure 1. Typical dual density toolstring, in a vertical well with breakout

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bore with breakout in one axis. The advantage of the dual-density tool configuration is obvious: although the measurements made by one of the tools may be affected by borehole breakout, the other density still acquires good data.

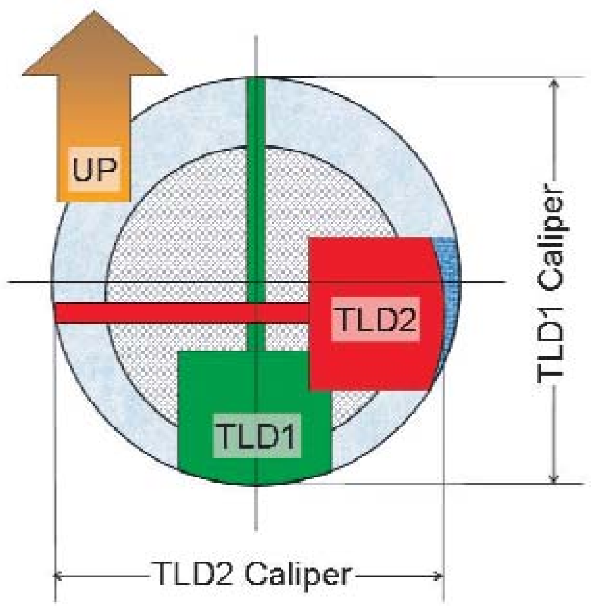

Figure 2. Typical dual density toolstring, inclined wellbore, no breakout

Figure 2 illustrates what happens with inclined wellbores. The important thing to note here is that, in deviated wells, there will be a tendency for one tool (TLD1) to turn into the low side of the hole. The weight of the toolstring tends to pull the other density tool (TLD2) towards the low side of the hole. Consequently, the TLD2 caliper makes an under gauge measurement, and the density skid exhibits poor pad contact with the borehole wall, degrading the density measurement.

Figure 3a combines wellbore inclination with borehole breakout. Here TLD1 is oriented pad down, but finds good hole and makes an acceptable measurement. TLD2 is affected by breakout and is also off-center in the hole. The resulting density measurement has reduced confidence (high density correction) and the caliper underestimates hole volume. However, as long as one tool is oriented toward the smaller axis of the hole, there is a good chance that there will be sufficient pad contact to make a viable density measurement.

Figure 3b illustrates another possibility in an inclined wellbore with breakout. As inclination increases, the tools may display a tendency to "fight" each other to go pad-down. As a result,

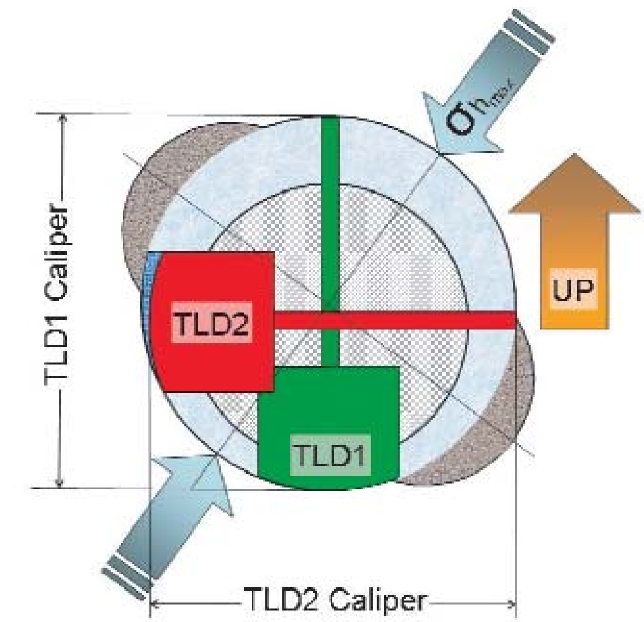

Figure 3a. Typical dual density toolstring, inclined wellbore with breakout, case 1

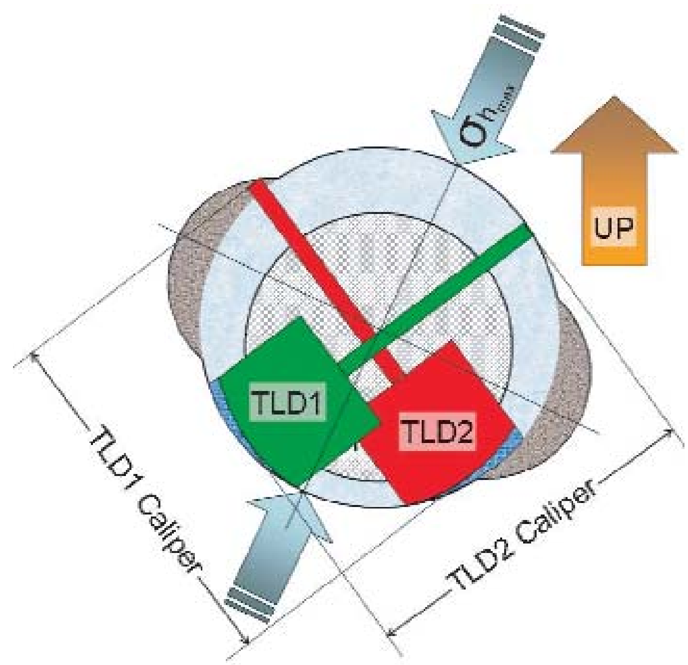

Figure 3b. Typical dual density toolstring, inclined wellbore with breakout, case 2

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both may end up deployed across a chord of the wellbore. Both calipers will read under gauge and neither tool will record trustworthy data. In such cases, it is generally preferable to run a single density tool, or close one density to allow the other to orient into the low side of the hole.

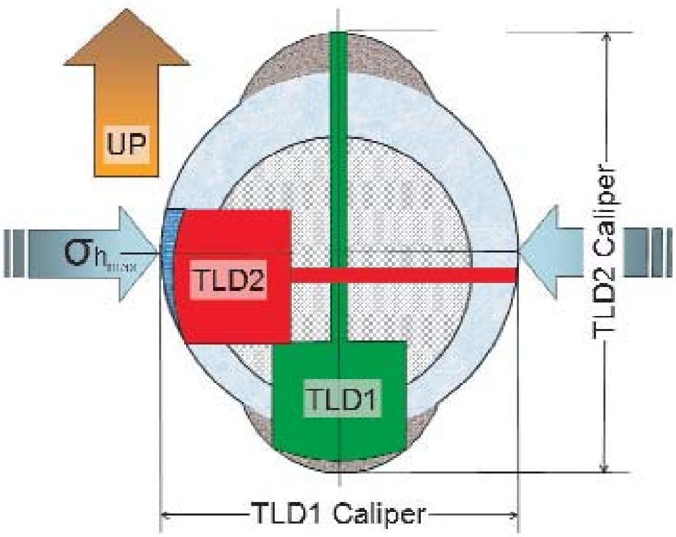

Figure 4. Typical dual density toolstring, inclined wellbore with breakout, drilled on strike

Figure 4 illustrates a situation in which it is doubtful that any useable data will be acquired by the typical tandem density toolstring. In this case, the well has been drilled in the direction of the least principal stress. One tool will go pad-down into the breakout and acquire bad density data. The other tool, although adjacent to smoother borehole wall, will exhibit poor pad contact, register an under gauge caliper and record density data that will most likely be of diminished quality.

The scenarios presented in the schematic diagrams underscore the importance of toolstring position. In many cases, although one (or both) of the density skids may be facing "good" (smooth) hole, eccentralization of the toolstring causes poor pad contact and prevents reliable density measurement from being made.

Log Examples and Discussion

The data presented herein deal with the implementation of a "powered positioning caliper " (PPC) into a tandem density logging string, in such a manner as to support and center the upper density tool. This configuration has led to an increase in the proportion of useable density data acquired per well. Furthermore, because the PPC design records four independent radii and incorporates a relative bearing measurement, the configuration has yielded some valuable insights into the nature of tool behaviour in deviated wellbores. Notably, it would appear that "centralization" of the toolstring (in the context of this document) is as important as trying to force or "lock" one density pad into the "good" side of the hole. In addition to improved bulk density measurements, the toolstring increases the accuracy of the calipers, yielding a more trustworthy calculation of hole volume.

Data from 28 wells was evaluated for this study. All were drilled with 200 mm bit size and oil-based drilling fluid. Directionally, there was a broad sample of wellbore paths. Four of the wells were chosen as examples for this paper. One is an example of a dual density run without the PPC, for comparison. For deviated wells in the study area, the data indicates that the primary (lower) density tool usually faces toward the "down" direction (lower quadrant of the wellbore). For consistency, we will refer to the primary density as the "down-density". The tool at 90-degrees will be referred to as the "side-density". Note that the corresponding density measurements from the tools are RHOZ (from TLD1) and RHOZ2 (from TLD2). Although the HDRA measurement from the TLD density tool is not a conventional density correction, for our purposes it is considered an indicator of density quality analogous to DRHO.

By correlating apparent breakout (as determined from the relative correction between the density tools) with pad one azimuth, it was confirmed that wellbores in the area of study consistently exhibit ovality, with the direction of elongation being oriented in a NW-SE direction (see figure 5). This was expected, as was the fact that vertical wells drilled in the area tended to drift to the NE (into the dipping strata).

Referring to the examples at the end of the paper, the log presentation used is intended to help understand the data with reference to the position of the toolstring in the hole. Track 1 is a correlation track, with gamma ray and ROP, as well as both of the density calipers. Track 2 is the resistivity data presented in

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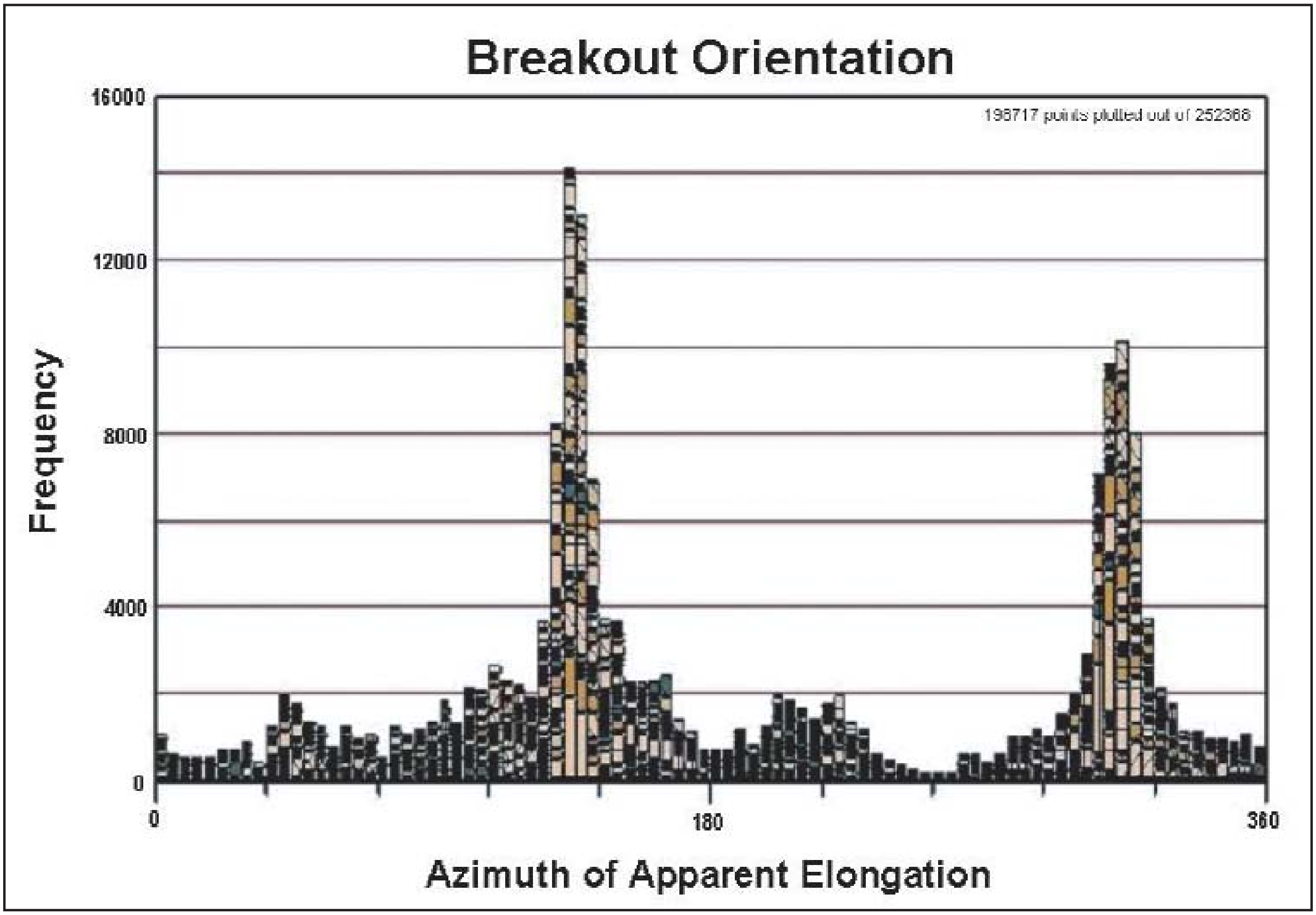

Figure 5. Direction of breakout observed in 28 wells, Ansell-Galloway area of Alberta

conjunction with the gas detector readings. Next, a porosity track contains the sonic travel time, neutron porosity and the bulk density data from both tools. The final track shows the PPC calipers and directional data, including the relative bearing of the primary density pad and the deviation measurement from the neutron tool. Hole direction and inclination from MWD tools (if run) are presented as green tadpoles for comparison with the red tadpoles, which represent the inclination and azimuth of the down-density pad.

Light grey shading is used when the side-density correction is greater than the down-density correction. Light green shading is used where the down-density correction is greater than the side-density correction. The density and PPC calipers are shaded in a similar fashion. This shading scheme allows us to quickly identify the breakout axis, as green shading should correspond to breakout on the top and bottom of the hole (i.e. along the same azimuth as the hole deviation) and grey shading should represent breakout on the side of the hole (perpendicular to hole azimuth).

Example #1 – Vertical Well

Well #1 (see Fig. 6) was a vertical well that drifted a little to the NE. Throughout the zone of interest, breakout is visible on TLD2, which has assumed a NW-SE orientation. At first glance, this example appears to show a change in the breakout direction, with breakout occurring in one axis of the hole in the sand, and in the opposite (orthogonal) axis for the overlying

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shales. However, scrutiny of the orientation data reveals that the toolstring turns by almost 90 degrees coming out of the sand. Therefore, the side-density (TLD2) sees the breakout in the sand and the down-density (TLD1) sees the breakout in the shales. This example demonstrates how toolstring behaviour is often unpredictable in response to varying borehole geometry. Nevertheless, for this well, the dual density configuration was successfully able to acquire good data throughout (most of) the zone of interest.

Example #2 – Northwest Deviated Well

Well #2 (see Fig. 7) was drilled to the NW with a bottom-hole inclination of about 10 degrees. No PPC was run and an LDS was used as the 90-degree density. The LDS caliper reads strongly under gauge and it appears to be riding below the centerline of the hole, as reflected in the high LDS correction values. Some breakout can be seen on the down-density (TLD) at the top of the sand. Given the regional stress orientation and the path of the well, the good axis should have been the "side" of the hole. Without a PPC to support it, the LDS did not achieve good enough pad contact to capture reliable density data. Luckily, it would appear that the lower portion of this wellbore did not develop particularly strong breakout, as evidenced by the low correction readings seen from the TLD. On the other hand, in the zone of interest, the breakout on the low side is significant and, consequently, the TLD correction looks very poor. It is interesting to note that although HDRA (the "correction" from the TLD) appears to be worse than DRH (from the LDS) in the zone of interest, the resulting TLD density measurements appear to be more reasonable than those obtained from the LDS.

Example #3 – Northwest Deviated Well

In well #3 (see Fig. 8) the orientation data shows that the down-density (TLD1) has locked into the low side of the hole. As expected from the prevailing NW-SE breakout direction, the resultant data is of poor quality. However, the PPC is hoisting the side-density (TLD2) into good contact with the smooth axis of the hole, and the ensuing density data is quite good. This is an example where it seems unlikely that good density could have been acquired, even with tandem density tools, without the aid of the powered positioning calipers.

Example #4 – Southeast Deviated Well

This example (Fig. 9) was also drilled along strike, but to the southeast. It may be expected from the extent of the rugosity displayed on both the density and the PPC calipers that it would be very difficult for any density tool to acquire useable data in this well. The fact that the TLD2 caliper agrees with the corresponding PPC caliper confirms that the PPC is supporting the side-density sufficiently to allow for a good density measurement to be made. It is apparent from the acceptable HDRA2 readings that the side of the hole is where the tool needs to be positioned in order to make a good density measurement. Without the PPC, this would not have happened.

Examples #3 and #4 illustrate how use of the PPC has enabled more dependable acquisition of formation density data and afforded a better understanding of wellbore geometry in three dimensions. For the data set under study, it was found that most wells display breakout along one axis. As such, the density tool

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Acquiring Density Data *… continued from page 14*

in that axis will not deliver accurate density readings. However, it will confirm the presence and magnitude of the breakout. The density tool in the opposite axis, more often than not, will offer a valid density measurement (or the best available).

On a number of occasions, experimentation was undertaken with opening only one of the density skids, to see if this would influence the path taken by the toolstring. Remarkably (or perhaps not so), it was found that, in most cases, the toolstring will lock into the same path on multiple passes, regardless of the wellbore inclination. In vertical wells, or wells with low inclinations (less than +/-3 degrees), tool orientation tends to be governed by the breakout axis. At higher deviations, gravity comes into play and the down-density (TLD1) tends to roll into a facedown attitude. This explains why moving the tool up and down in moderately inclined wells often fails to persuade the density tool to take the "good" axis.

In some cases, both axes of the hole exhibit deterioration and valid formation density data is inaccessible. Running the PPC helps to deal with the troublesome question of whether good density data was even available. Knowing this, in itself, is useful information. In deviated wellbores, without the PPC, if both density calipers read under gauge (as is often the case) then we are unsure as to whether there is breakout (or washout). When the PPC is run, the density tools are more likely to "see" the true hole geometry. Even so, despite the orthogonal orientation of the density calipers, they do not make simultaneous measurements at the same depth, and any inferences with regards to hole geometry are therefore subject to error due to tool rotation. The PPC, by contrast, measures four independent and instantaneous radii, providing very good verification of hole geometry.

It is interesting to note that some of the studied wells show very little breakout through the interval of interest. In other wells, the pay interval(s) appear to exhibit significant breakout (as opposed to washout) in both axes. A potential avenue for further investigation would be to check the production rates of these wells to see if there is any correlation between hole failure and inflow performance.

Conclusions

Until recently, it would seem that the prevailing mind-set for obtaining reliable density data in elongated wellbores has been to use mechanical means to forcibly lock one side of the toolstring into the long axis of the wellbore. Tandem density logging improves on this by adding another density skid at 90 degrees, with the expectation that one of the tools will encounter a smooth borehole wall. Logging companies have therefore designed toolstrings and running gear with an eye to accomplishing this end. For the most part, they have met with a good deal of success. Certainly, when logging vertical wells, the majority of the logging contractors operating in the WCSB can field toolstrings that offer a reasonable probability of acquiring valid density data. However, when wellbores deviate (by accident or design) with inclinations as small as 3-4 degrees, the results obtained from these toolstrings can become somewhat hit-and-miss.

As regards the tandem density toolstrings currently available to the industry, at higher angles of deviation (greater than +/- 10 degrees) it may be more cost effective to stick with conventional, single-axis density tools. In wells drilled directionally along the orientation of the principal minimum stress, there may be very little chance of getting a reliable density from any of the commonly utilized tool combinations. In all wells evaluated so far, regardless of inclination or direction, the addition of certain hardware (such as the PPC) to aid in proper orientation/positioning of the toolstring has increased the proportion of quality bulk density data acquired. Moreover, the understanding of the underlying conditions relating to the acquisition of the log data has been greatly enhanced.

The following recommendations are put forward towards increasing the probability of acquiring high quality density data in elongated, directional boreholes drilled through stressed formations. They apply for inclinations of up to 20 degrees in

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Acquiring Density Data *… continued from page 15*

wells that exhibit elongation of the borehole (such as those along western flank of the WCSB), and especially if drilled along strike (into the minimum principal stress direction). The following strategy is proposed:

1. Run a toolstring that combines two density tools in an orthogonal orientation.
2. Configure the tools and related running gear in such a fashion as to emphasize centralization and support of the density tools in order to permit the density skids to deploy fully across the entire diameter of the wellbore, thereby optimizing contact with the borehole wall.

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Acknowledgments

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Acquiring Density Data *… continued from page 16*

Appendix A – Logging Procedures and Operational Recommendations for Running Tandem Density Toolstrings

What follow are some of practical procedures for consideration when running tandem density toolstrings:

- Ensure that the PPC is placed in the toolstring directly under the upper density (TLD2), as close to the density measurement skid as possible (see Fig. 10). In wells with higher inclination, it may be advantageous to incorporate more than one PPC into the toolstring (although this has not been investigated so far).
- Run the PPC with all arms extended at maximum pressure (full power, level 4) to ensure centralization of the side-density tool (TLD2).
- Exercise caution when interpreting relative bearing readings. The raw relative bearing is dependent upon the toolstring configuration. Our recommendation is to run a relative bearing check with the toolstring hanging in the derrick.
- If logging passes off bottom do not show good density data, then try a repeat with only the down-density tool (TLD1) open (all other calipers closed). Changing the downhole forces acting on the tool may move it into a different orientation with better pad contact.
- It is advisable to make a minimum of three passes over the zone(s) of interest (if sufficiently close to the bottom of the well) to help wipe the hole and minimize the effect of any debris, as well as to verify any unexpected log responses. Two passes leave you in an either/or situation – a third pass should confirm one response or the other.
- When running tandem-density configurations, the use of same-generation density tools eliminates potential questions as to the source of any discrepancies between tools (i.e. there can no debate as to whether observed differences in tool response are related to tool type or caused by borehole geometry/tool attitude).

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Acquiring Density Data *… continued from page 17*

- When in smaller holes (e.g. 156 mm) 90-degree hardware cannot be run on the neutron, and a swivel head may help to limit tool rotation. It may be that a swivel head is helpful in any hole size. We have not endeavoured to investigate the efficacy of the swivel so far, but we did log one well (outside the study area) using a dual-density toolstring with the PPC but without a swivel. The hole size was 156 mm and the toolstring exhibited rotation (normally related to cable torque) even though the wellbore inclination was in the order of 20 degrees.
- Initially, we were not sure of the influences on tool rotation. After reviewing the data from these wells, we are now of the opinion that, when the PPC is used and functioning correctly, borehole ovality caused by stress-induced breakout will tend to be the dominant factor affecting tool orientation.

- Logging tool orientation measurements are generally not reliable below about 2-3 degrees of inclination. This is a tool limitation and it is often noticeable when comparing MWD data with wireline. At higher angles, the agreement on most wells was very good. On a few wells there may have been calibration issues.
- At very low deviations, the relative bearing may be influenced more by the attitude of the PPC in the toolstring than the actual borehole direction. Relative bearing is measured in the PPC, which is assumed to be centered in the hole. In reality, the PPC will not be positioned at the exact center of the hole. Fortunately, it is possible to use the four individual radii measured by PPC caliper arms to determine how far off center the tool is really located. Certain components of the toolstring (such as the sonic) are designed to be run centered in the wellbore. Others are meant to be eccentered (such as the AIT and the density tools). Even with knuckle joints in the toolstring, the resulting moment influences on the PPC can pull either end of the tool out of alignment with the true borehole axis. So, if the wellbore inclination is very low, and especially in large or washed out holes, the PPC may actually end up leaning in a different direction than that of the wellbore (albeit only 1 or 2 degrees out of vertical). In such a case, the recorded PPC relative bearing will appear to be at odds with everything else the logging tools are telling us. This explains why we apparently observed breakout in the wrong axis in two vertically drilled wells. It is recommended that the individual radii from the PPC calipers arms be recorded to the log data files, as they may be an invaluable reference in such cases.
- An alternate service provider was used for a number of wells evaluated. No equivalent of the PPC was available at the time of logging and, as may be expected, the data acquired suffers from poor pad contact in the deviated section of the hole. The density tools tend to read under gauge in both axes, yielding a positive density correction of more than 50 kg/m3 throughout the log. An extra run was performed in one well with additional offset joints in the tool string. The ensuing data was better, but still not optimal. Although the density measurements repeated well, the calipers remained under gauge and correction was still too high. Similar results were obtained when the tandem TLD/LDS toolstring was run without the PPC. The service company in question is presently working on potential solutions to better support and centralize the second density tool.

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Acquiring Density Data *… continued from page 18*

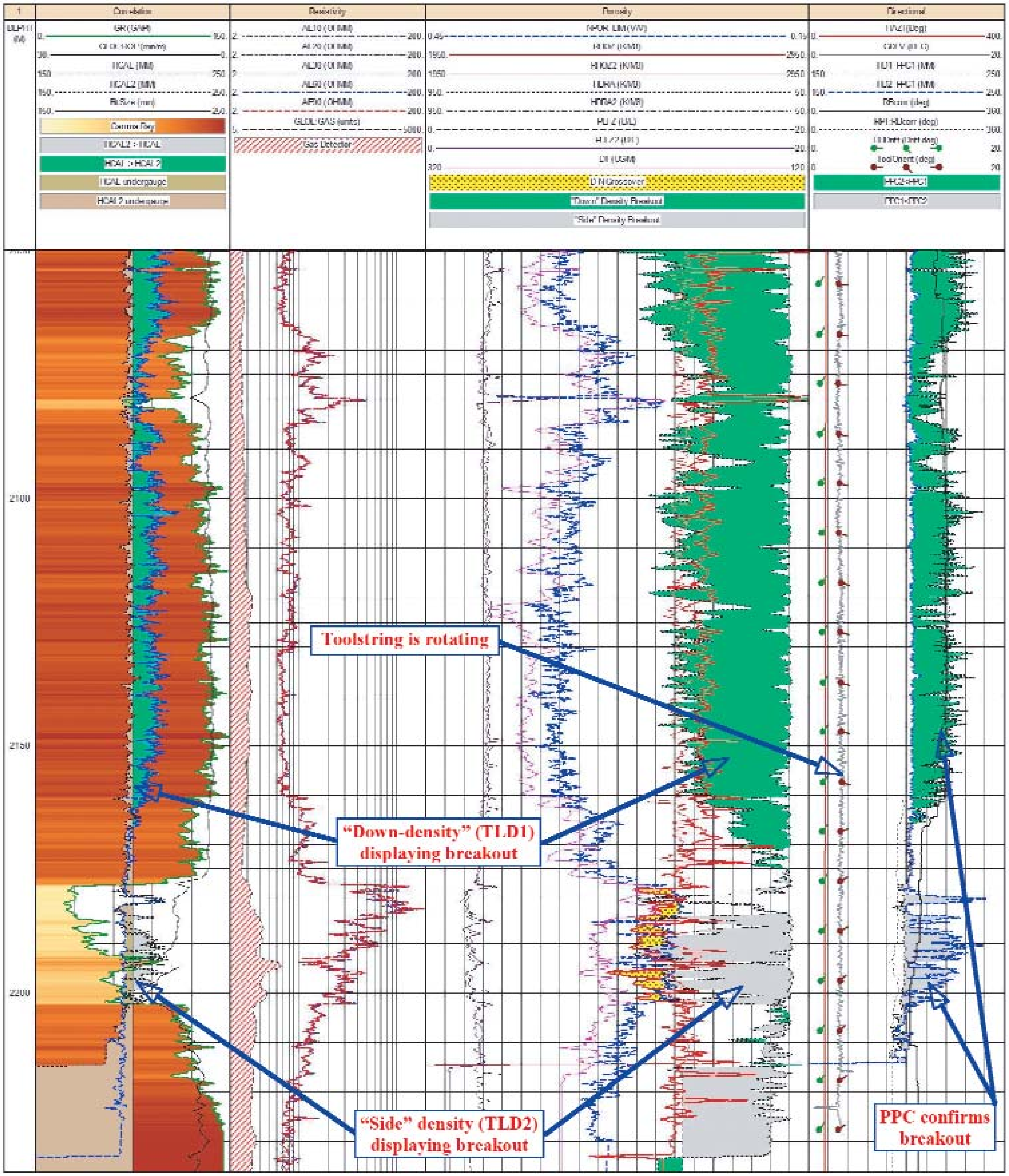

Figure 6. Log example #1

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Acquiring Density Data *… continued from page 19*

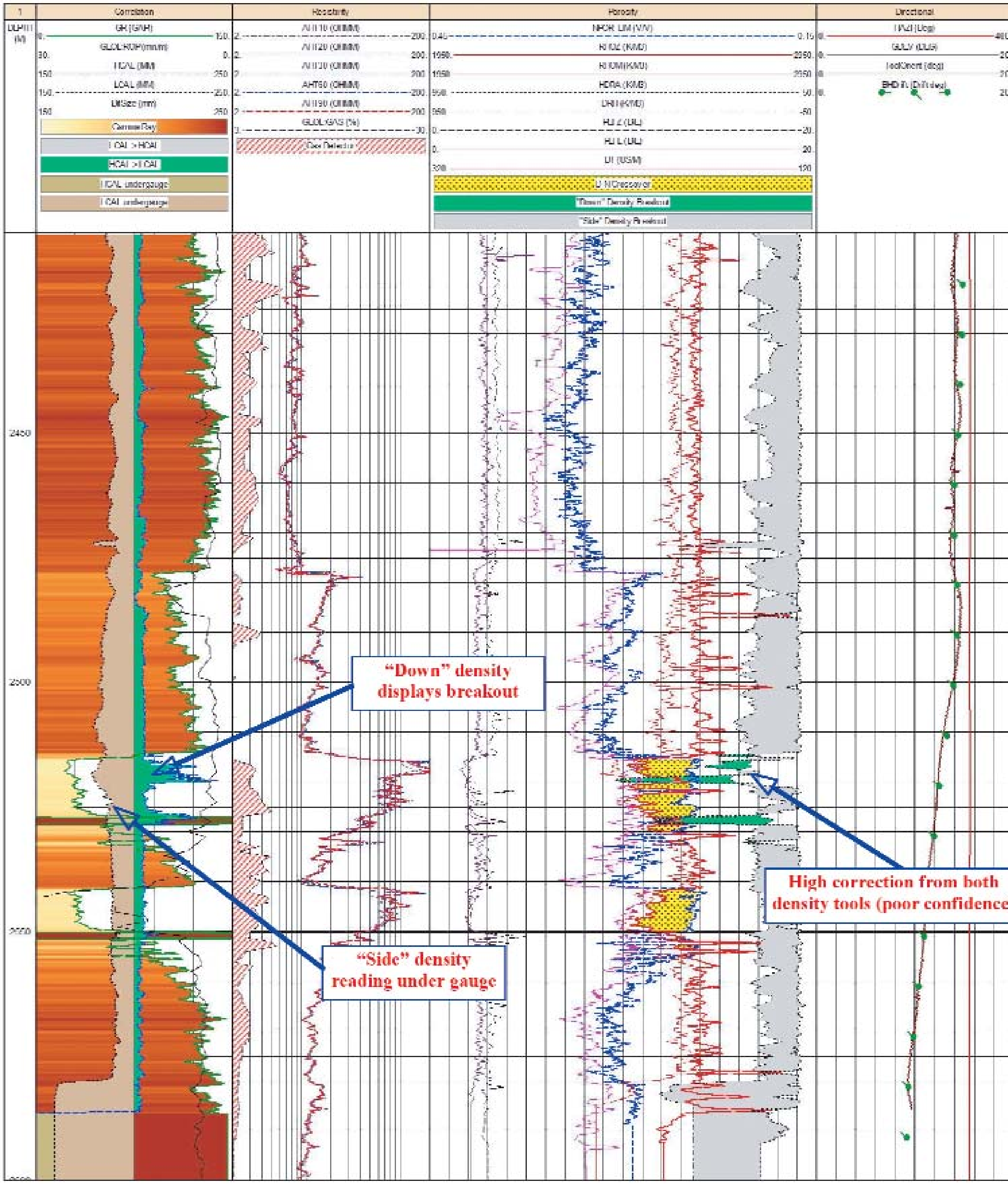

Figure 7. Log example #2

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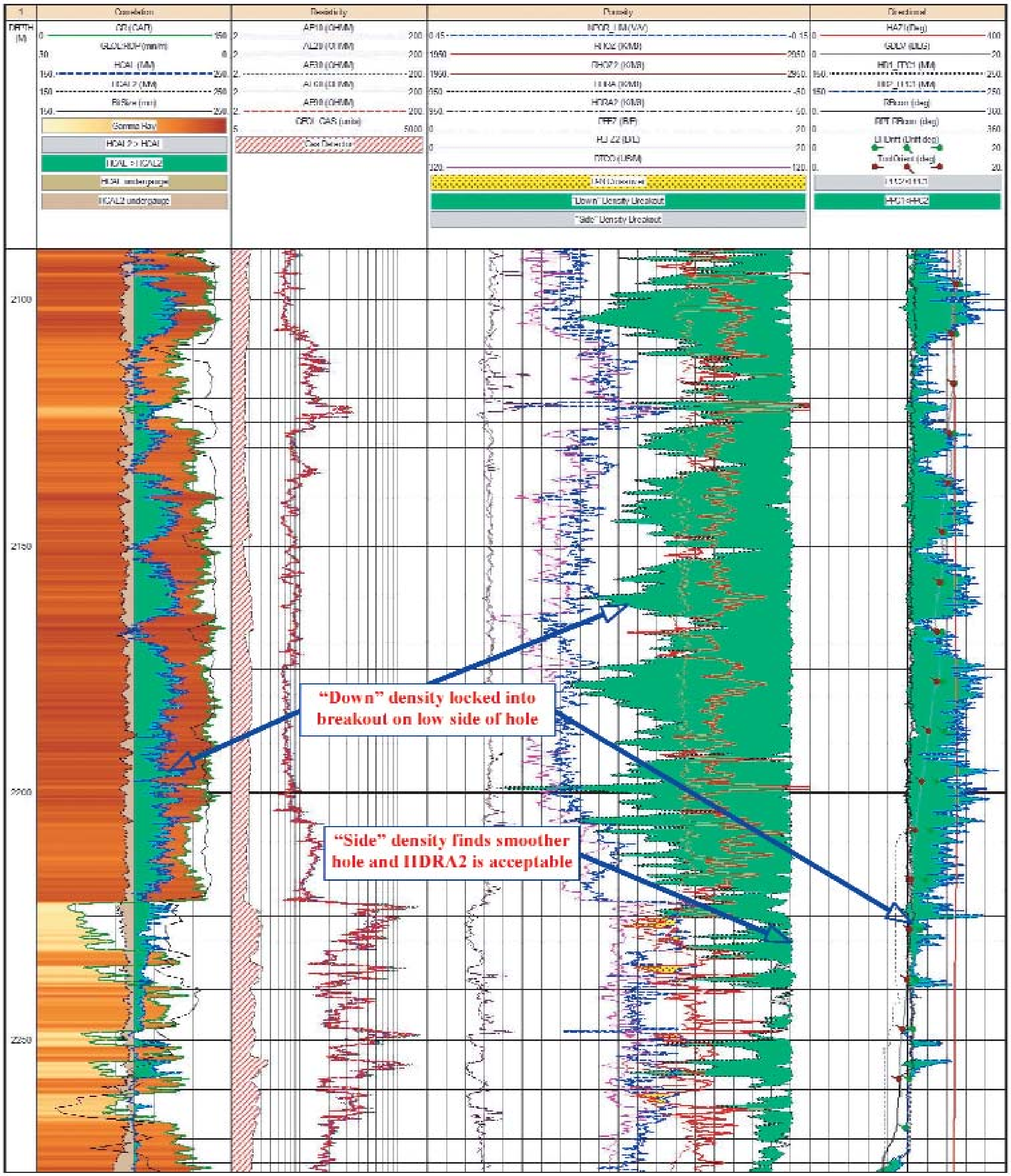

Figure 8. Log example #3

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Acquiring Density Data *… continued from page 21*

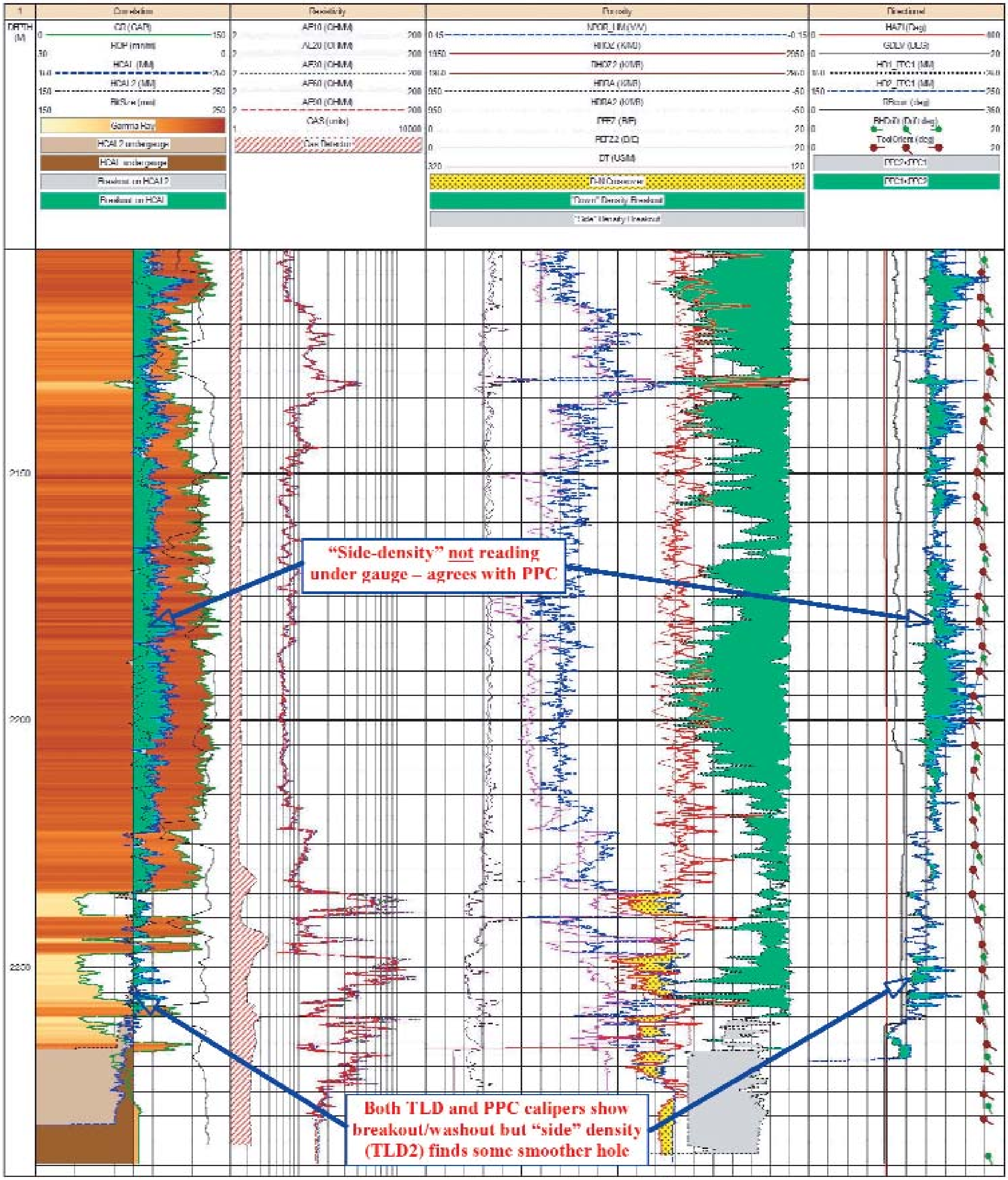

Figure 9. Log example #4

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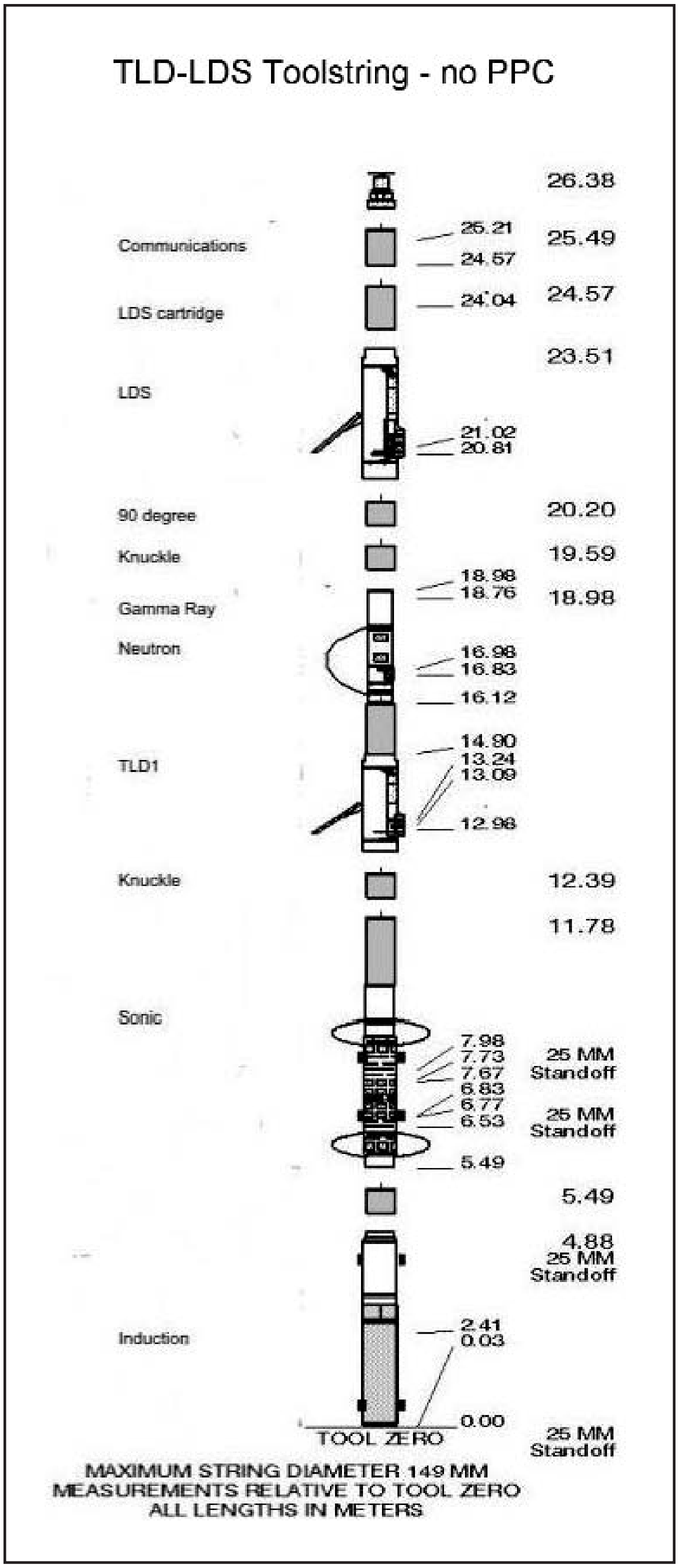
Acquiring Density Data *… continued from page 22*



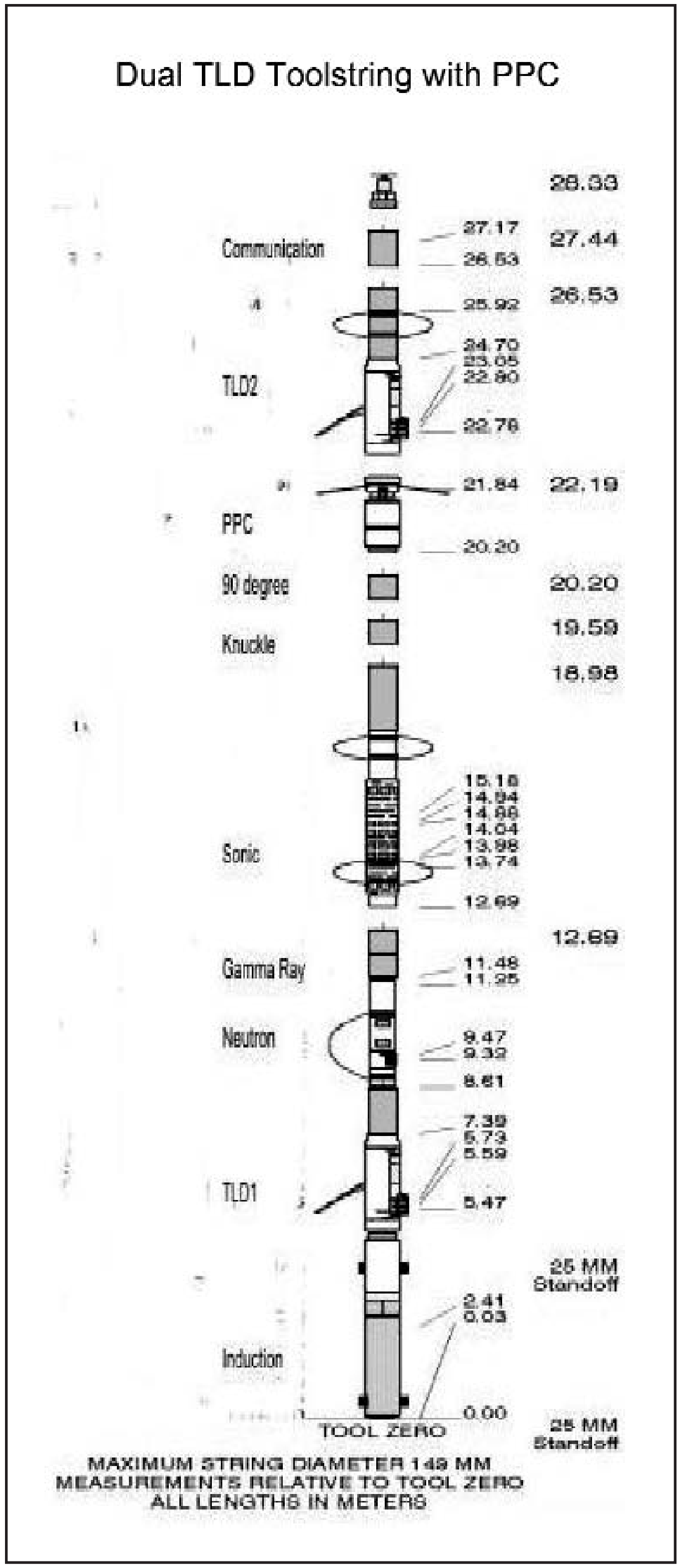


Figure 10. Typical Schlumberger Tandem Density Tool Strings with and without PPC™

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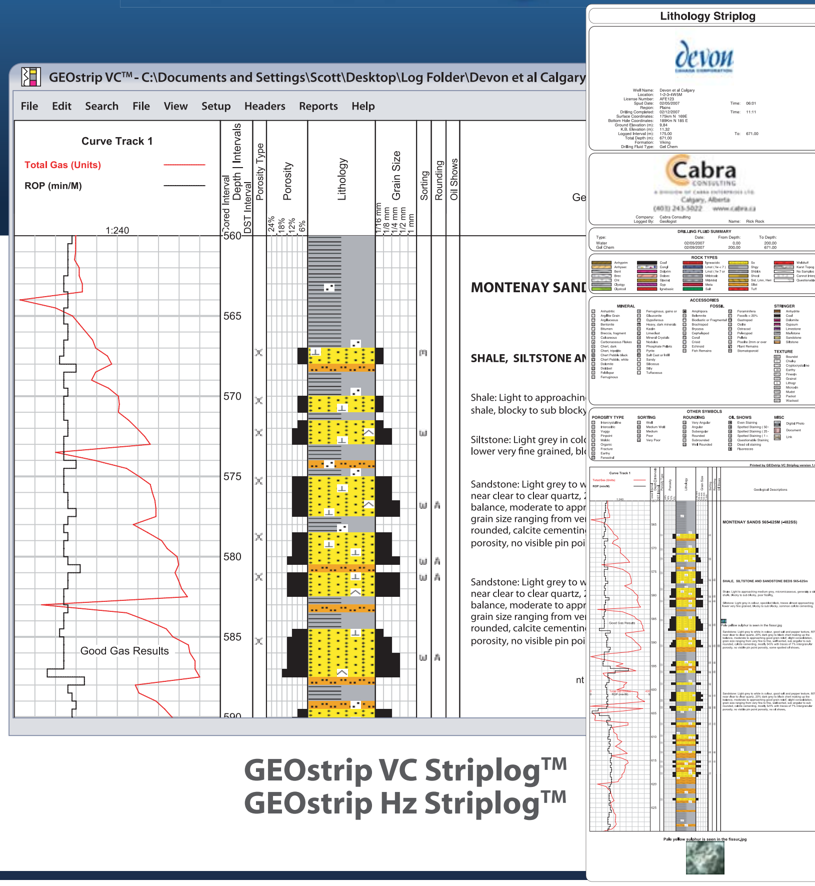

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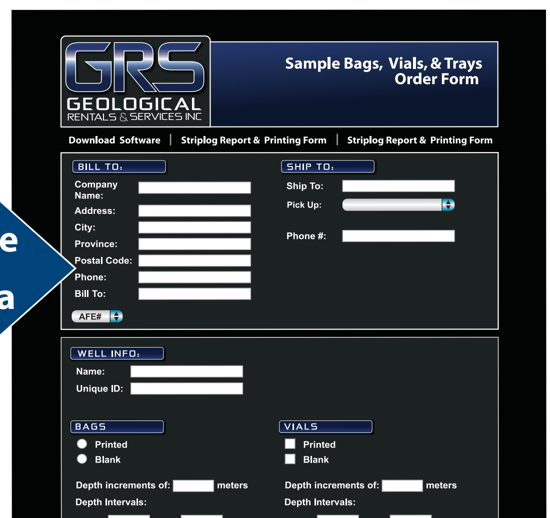

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Low Permeability Gas Reservoirs How Low Can You Go?

Mike Miller, Bob Lieber, Gene Piekenbrock and Thal McGinness
BP America Production Company, North America Gas Strategic Performance Unit

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Abstract

Increased focus in tight gas reservoirs has stirred a debate concerning potential uncertainties in determining gas in place and recoverable gas. There are questions concerning the reliability (accuracy and reproducibility) and applicability of routine and special core analysis measurements to the in-situ rock. Small pore volume and the low flow capacity make these rocks particularly sensitive to measurement errors and make it difficult to reproduce in-situ conditions.

A survey of some recent literature provides a glimpse at the state of the art in low permeability core analysis procedures.

Recently, it has been shown that the most commonly used unsteady-state technique over estimates permeability. The differences are most significant for permeability less than 0.01 md. Legacy data for rocks with permeability of less than 0.01 md will be biased high, potentially by up to an order of magnitude.

Multiphase permeability measurements are more difficult to conduct than single phase measurements. Recently published data show a wide variability of permeability reduction with changes in wetting phase saturation. Modeled gas recovery varies by more than 30 percent based on these data.

Differences in irreducible water saturation from capillary pressure curves exist depending on test method. Uncorrected high-pressure mercury injection data often inaccurately characterizes capillary pressures at irreducible water saturation. Typically, higher irreducible water saturations are seen from capillary pressure curves using vapor desorption data and high-speed centrifuge or high-pressure porous plate data in low permeability rocks.

Formation water salinity can show significant variability (+/- an order of magnitude) when reconstructed from a Dean Stark analysis. Water resistivity and saturation in core is difficult to measure in rocks with low total pore volume.

Archie saturation exponent (*n*) can vary depending on analysis technique. Single point versus multipoint resistivity index measurements and test duration can have a large effect on saturation exponent. These tests can take weeks/months instead of days to become stable.

The prudent evaluation of low permeability rocks worldwide requires the ability to understand and limit these and other sources of petrophysical uncertainty.

Introduction

Unconventional gas reservoirs are a growing part of the total production in the United States (figure 1, EIA, 2006). Low permeability gas reservoirs are by far the largest component and are becoming increasingly important as a global resource.

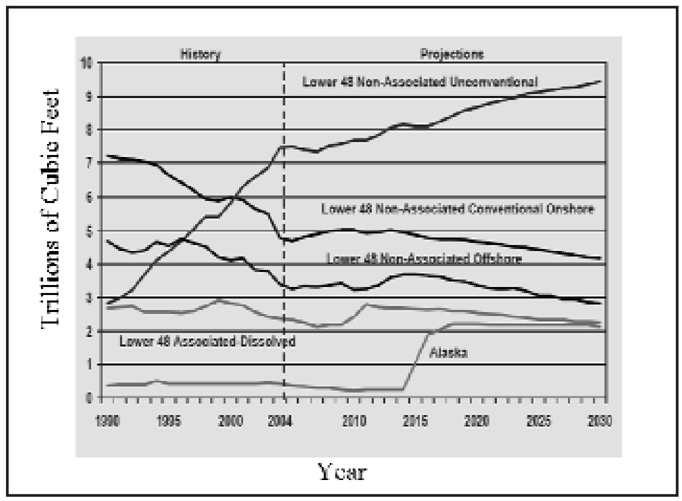

Figure 1. Historic and future trends for natural gas production in the USA.(http://www.eia.doe.gov/oiaf/archive/aeo06/pdf/trend_4.pdf).

A low permeability reservoir rock is defined as having permeability less than 0.1 millidarcies for this study. Most of the porosity in these rocks is split between remaining primary pores and secondary pores created by grain dissolution. Narrow slot like pore throats (figure 2) provide the flow path by connecting the primary and secondary pores (Dutton et al., 1993).

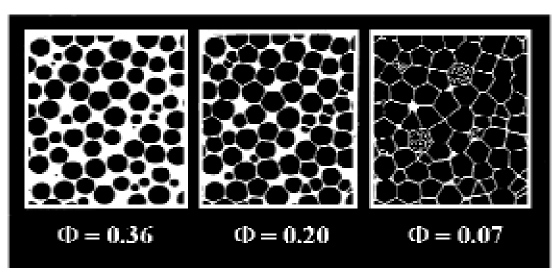

Figure 2. Typical grain and pore arrangement from high primary porosity rocks with relatively uniform pores to low porosity rocks having abundant slot (high aspect ratio) pores (after Roberts and Schwartz, 1985)

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Low Permeability Gas Reservoirs *… continued from page 25*

Wireline-log analysis of low permeability gas reservoirs is complicated by numerous factors. These factors include but are not limited to; uncertainty in Archie or shaley sandstone parameters, lack of formation water data, mud filtrate invasion, clay content, and grain density. Reservoir properties are developed using an empirical relationship between the logs and in-situ core analysis measurements (Byrnes and Castle, 2000).

In-situ core analysis data needs to be used as ground truth in these petrophysical analyses instead of ambient pressure data. Questions remain however, about the reliability (accuracy and reproducibility) and applicability of these measurements to the in-situ rock. Small pore volume and the low flow capacity make these rocks particularly sensitive to measurement errors and make it difficult to reproduce in-situ conditions.

The absolute uncertainty may remain high in these rocks, even when great care is used in our analysis technique and methods. Many of these reservoirs have properties at or below the current limit of our ability to accurately measure them.

As the industry moves to exploiting rock of lower and lower quality (gas shales in North America for instance), there needs to be renewed scrutiny of laboratory and wireline quality and results (Al Ruwaili, 2005). Some recent published data for gas shales shows productive intervals with ambient air permeabilites of less than a nano darcy.

Uncertainty of up to 30 percent of recoverable gas will be shown using data from recent tight gas publications and proprietary data. There are potentially issues with both core and wire-line data accuracy and reliability.

A number of questions arise upon closer examination of core data recently presented (Rushing et al, 2004, Newsham et al, 2004 and Laswell et al, 2005) for low permeability rocks:

1≥ Are these rocks amenable to an Archie type analysis or is something else required?

2. Do core analysis standards need to be redefined for low permeability reservoirs?

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Low Permeability Gas Reservoirs *… continued from page 26*

3. What is the ability to get these rocks back to in-situ conditions?
4. Are artifacts created in the core as it is handled?
5. What can be done with legacy data, if problems exist with current analysis techniques?

One cannot expect to look at every possible core or log analysis issue relating to low permeability reservoirs. Neither can answers to all of the questions posed above be obtained. However, examples of uncertainty in; porosity, permeability, relative permeability, formation water salinity, core water saturation, capillary pressure and resistivity index, will be presented from some recently published examples and some recent proprietary core analysis.

Porosity

Porosity remains relatively constant even when samples are returned to net overburden conditions in low permeability rocks. A (+/-) 0.2-0.3 porosity unit uncertainty is observed in laboratory analysis techniques. Determining porosity from logs probably has a higher uncertainty than issues related to laboratory techniques.

Helium porosity at in-situ conditions tends to be at 95 percent of the values measured at ambient conditions in reservoir quality low permeability rocks (Byrnes, 1997). This minor response of pore volume is consistent with the idea that slot pores may compress under stress and make up only a minor portion of the overall pore volume. The well-cemented and rigid framework typical of these rocks is also consistent with this premise.

Porosity reproducibility is (+/-) 0.2-0.3 porosity units at stressed conditions as defined in the American Petroleum Institute Recommended Practices for Core Analysis (RP40). This will only result in a minor amount of uncertainty when calibrated with logging tools.

The largest uncertainty in porosity is likely to be the accuracy of the wire-line tools. Accuracy specifications are not well developed in the logging industry (Theys, 1997). Accuracy within 1 porosity unit would not necessarily be considered a problem in an 18 to 22 percent porosity rock. Much higher accuracy is demanded for low permeability reservoirs with porosities between 5 and 10 percent however.

Permeability

Permeability at in-situ conditions can be lowered by more than an order of magnitude compared to values measured at ambient conditions (Byrnes, 1977). The estimate of in-situ single phase permeability from the commonly used unsteady state (USS) permeameter was higher by as much as a factor of two until the error was presented in 2004 (Rushing et al, 2004) and corrected by most of the major laboratories in the U.S.

Routine core analysis permeability data are normally conducted at relatively low pressure (approximately 0300 psia, also called ambient conditions). They are usually single-phase analysis (100% gas saturation, 0% brine saturation). This is typical of our legacy data in North America.

The Klinkenberg (or slippage) corrections are applied to these measurements to account for the difference in gas behavior at the low pressures seen in the laboratory versus the high pressures seen in the subsurface (Bass, 1989). These corrections can reduce routine permeability measurements by as much as a factor of 3 for samples with routine permeabilities less than 1 md (Byrnes, 1997). Permeability measurements that have been adjusted for slippage effects are commonly referred to as equivalent liquid permeability.

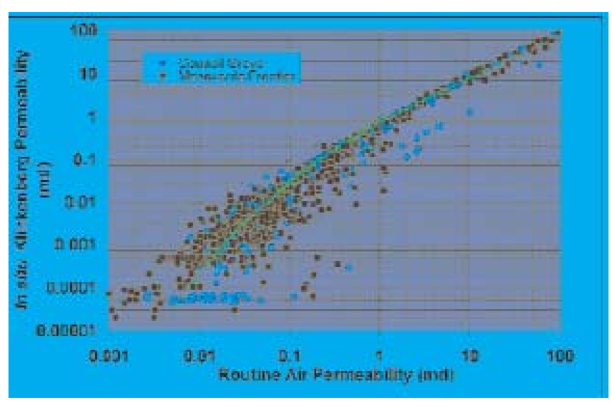

Figure 3. Crossplot of routine air versus in-situ Klinkenberg permeability for Mesaverde-Frontier sandstones (squares) and Council Grove carbonates (circles). Note the increasing influence of confining stress on samples with decreasing permeability. (Byrnes, 2005)

Laboratory permeability measurements are particularly susceptible to increases in overburden stress (figure 3). The greatest response to increasing overburden stress is attributed to rocks with slot pores and pore throats (Davies and Davies, 1999). Pore throats in low-permeability sandstones could decrease by 50 to 70% with increasing overburden stress (Byrnes and Keighin, 1993, reported in Byrnes, 1997).

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Low Permeability Gas Reservoirs *… continued from page 27*

Recently it has been reported that the most commonly used unsteady-state (USS) technique consistently over estimates permeability (Rushing, et al, 2004). Permeabilities were compared from the USS permeameter (klinkenberg corrected to equivalent liquid permeability) versus actual liquid permeability in the same samples (figure 4). The differences are most significant for permeability less than 0.01 md. This brings in to question all of the legacy data for low permeability rocks that do not have actual liquid permeability measurements. This analytical error has been corrected in the major laboratories in North America (figure 5). But there is no single "fix" to correct legacy data measured prior to 2005.

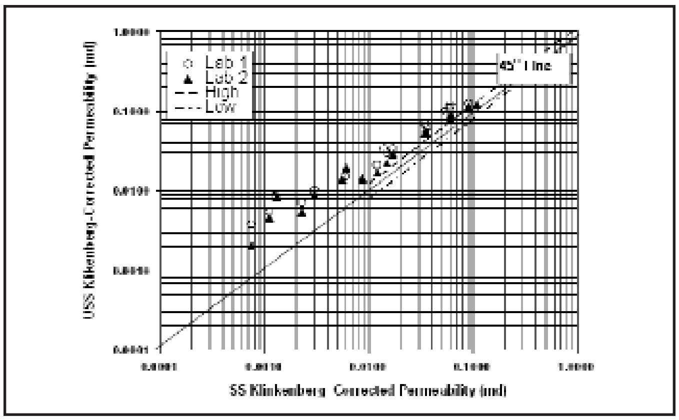

Figure 4. A comparison of steady-state (SS) and unsteady-state (USS) Klinkenberg-corrected permeability (Rushing et al, 2004). High and Low are the analytical confidence intervals from Thomas and Pugh (1998).

Confidence interval, % with probability of:

kg range millidarcys	68.3%	95%	99%
0.01 - 0.1	+/- 8%	+/- 16%	+/- 21%
0.1 - 1.0	8	16	21
1.0 - 50	5	10	13
50 - 1,000	3	6	8

Table 1. Statistically derived confidence intervals of conventional steady-state measurements performed by many laboratories all over the world on a standard set of plugs. (99% confidence interval data from Thomas and Pugh 1989, table from API RP40).

Permeability reproducibility is defined in table 1 from the RP40 (and Thomas and Pugh, 1989). The lowest standard measured in this study was 0.01md and there are only two samples below 0.1md. Most of the rocks currently exploited as tight gas have permeabilities much lower, and the industry continues to try to produce gas from even poorer quality rocks. Some gas shale reservoirs have permeability measured in the nano darcies.

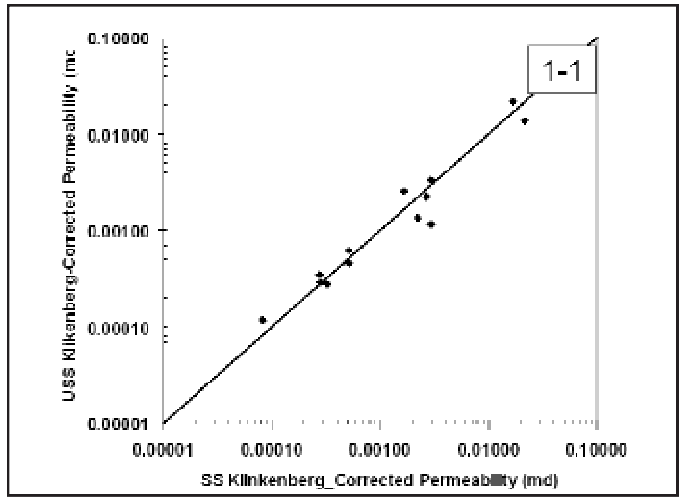

Figure 5. Comparison of steady-state (SS) and unsteady-state (USS) Klinkenberg-corrected permeability for a recently cored low permeability gas well in Wyoming, USA.

It is clear that the effects of increasing overburden pressure are greater than the analysis issues illustrated by Rushing et al (2004). These analytical differences however, could be very significant in rocks with permeability less than 0.01md. These results point out a fundamental flaw in the way the data were being analyzed. This raises additional questions; 1) Do other more complicated measurements also have measurement and/or protocol flaws, 2) Do we need to establish new standards for low permeability rocks?

Relative Gas Permeability

Gas relative permeability at in-situ conditions can be lowered by 3 orders of magnitude compared to single phase values (Shanley et al, 2004). A difference of 30 percent recoverable gas can be modeled from the variability observed in these measurements.

Low-permeability reservoir rocks suffer from the combined effects of overburden stress and partial brine saturation (Shanley et al, 2004; Thomas and Ward, 1972; Byrnes et al. 1979; Jones and Owens, 1980; Dutton et al., 1993; Byrnes, 1997, 2003). Permeability measured in the laboratory at reservoir pressure and saturation, range from 10 to 10,000 times less than routine gas-permeability values measured at ambient conditions. This

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Low Permeability Gas Reservoirs *… continued from page 28*

decrease is largely caused by the combined effects of gas slippage (Klinkenberg correction), confining stress, and partial brine saturation and its influence on effective permeability.

Relative permeability is defined as the ratio of the effective permeability of a fluid at a given saturation to the fluid permeability at 100% saturation (Archer and Wall, 1999). There is little consistency in the literature regarding the reference fluid used to determine relative permeability. Care must be taken to ensure that data are reported with consistent reference fluids when comparing legacy data.

Recoverable gas estimates are uncertain when determined from highly variable relative permeability data. It is difficult to measure relative permeability in low permeability rocks due to the stress and saturation issues raised above. It is also difficult to know if there is a uniform saturation along the length of the sample as it is being tested.

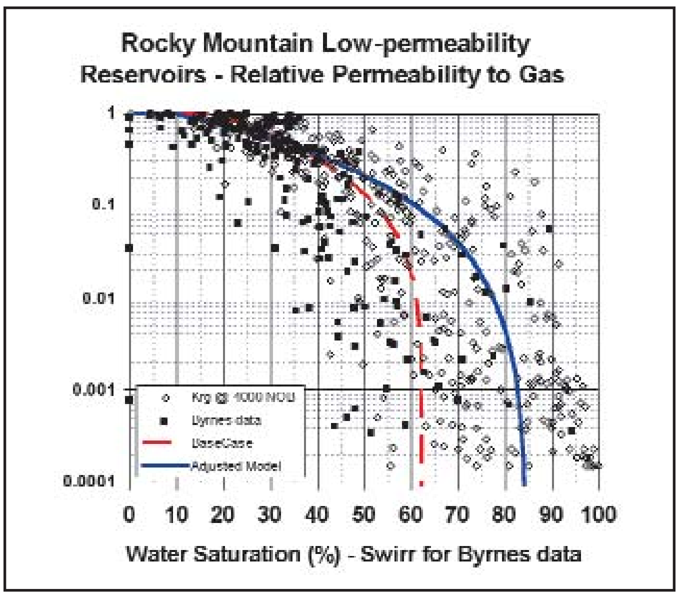

Figure 6. Relative permeability of gas plotted against water saturation. 30 percent difference in recoverable gas is modeled using the functions represented by the "Base Case" and "Upside Case" lines. Data from Shanley et al, 2004.

Relative permeability data from low permeability rocks in the Greater Green River Basin (Wyoming USA) are plotted in figure 6. Reservoir modeling is used to look at the uncertainty associated with recoverable reserves based on the range observed in the relative permeability data. There is 30 percent uncertainty in the calculated recoverable hydrocarbon volumes when the expressions for relative permeability for the base case and the upside case are used in the simulation. Many tight gas reservoirs cover vast areas and this translates into uncertainties of 10's of trillions of cubic feet of recoverable reserves.

Water Resistivity and Core Water Saturation

Formation water salinity can vary by an order of magnitude when reconstructed from a Dean Stark analysis. Water saturation for core is also difficult to determine for low permeability rocks with a low total pore volume.

Water resistivites are determined by extraction from core or measured from produced waters. Core water resistivity is difficult to obtain in low permeability rocks due to their low total pore volume. Often, no water is recovered from core extraction techniques in low permeability rocks. Water salinity values are then determined from recombined total water captured from Dean Stark extraction. Produced water from gas wells cannot be used because they are diluted with water of condensation, and it is difficult to determine the differential volume of condensed water.

For a recombined analysis of water saturation and salinity, the total amount of water is derived from a Dean Stark analysis. The amount of clay bound water is determined from bench top nuclear magnetic resonance (NMR). The amount of imbibed drilling fluid in the core is determined from a tritium tracer added to the mud to tag the drilling fluid. The difference of the total water minus imbibed water minus the bound water equals the in-situ water saturation.

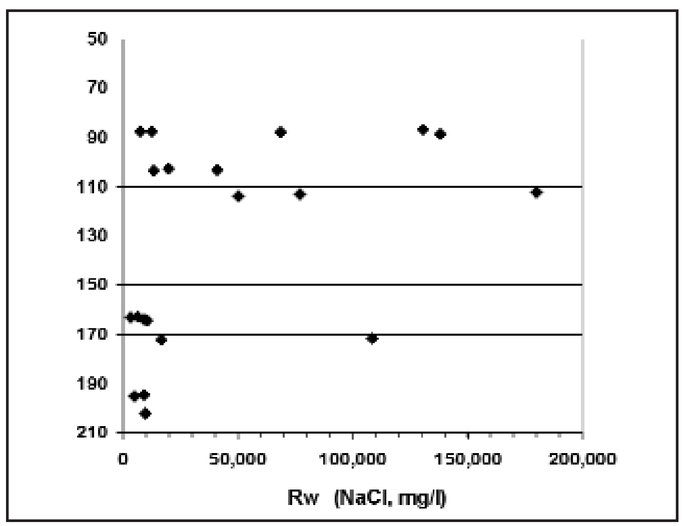

Figure 7. Measured depth below top reservoir plotted against calculated formation water resistivity.

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Low Permeability Gas Reservoirs … *continued from page 29*

The water resistivity is then determined from the formation water fraction. The results of this analysis (figure 7) suggest variability in formation water salinity with depth. Notice the high salinity for the shallow part of the section and a salinity decrease lower in the section. Taken at face value, the average formation water salinity can potentially be broken out into at least two gross regions with different average salinities. If valid, the differences in salinity may also suggest that some barrier or baffle exists that keeps these waters from equilibrating.

In this case however, salinity differences can be shown to vary with the volume of formation water extracted from the core (figure 8). Samples with low formation water recovery (less than 0.5cc) have much higher water salinities than samples with higher volumes of formation water recovery. Since Dean Stark extraction has 0.1cc error associated with water volume, the uncertainty in water saturation and formation water salinity will be large if only minor amounts of water are extracted from the core. Applying this data without scrutiny, could lead to errors in both core water saturation and formation water salinity.

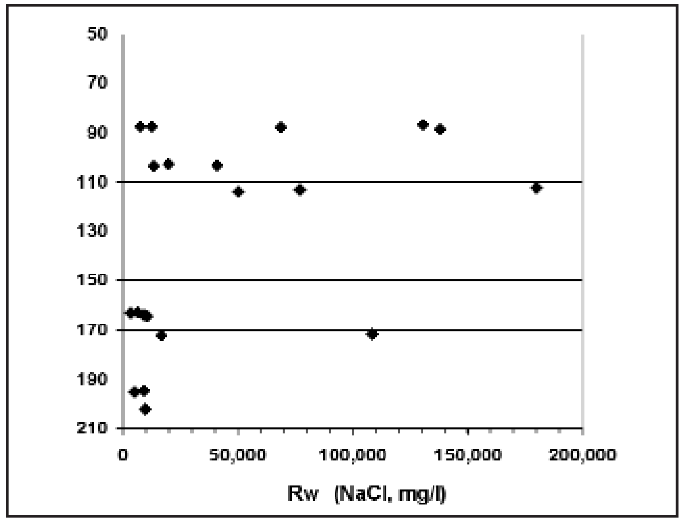

Figure 8. Calculated salinity plotted against the volume of formation water extracted.

Continued on page 31…

Red Sand Beach Hana, Maui
Photo Courtesy of Mark Pfeifer

Low Permeability Gas Reservoirs *… continued from page 30*

Capillary Pressure and Irreducible Water Saturation

Irreducible water saturations can vary by an order of two depending on the analysis technique. Large uncertainties in calculated gas column height can occur due to errors in determining core water saturations and in irreducible water saturations determined from high pressure mercury injection (HPMI) capillary pressure.

Pore geometry and pore-throat distributions are commonly made using capillary pressure measurements (Yuan and Swanson, 1986; Jennings, 1987; Spencer, 1989; Vavra et al., 1992; Dutton et al., 1993). Pore throats are often less than 0.1 m in diameter (Hartmann and Beaumont, 1999) and capillary pressures are high at relatively moderate wetting-phase saturations in low permeability rocks. Irreducible water saturation is defined as the water saturation at which further increases in capillary pressure produce little to no additional decrease in water saturation.

Irreducible water saturations vary by a factor of two depending on the analysis technique (Newsham et al, 2003). The differences are seen when comparing data on the same rock using both HPMI and centrifuge combined with vapor desorption data (figure 9). Newsham et al, suggest that capillary pressure curves using vapor desorption data and high-speed centrifuge or high-pressure porous plate data appear to provide a more accurate measure for irreducible water saturation in tight rocks.

These differences will affect the calculation of gas in place when calibrated with the logs. Calculated gas column height will also be affected by the differences in irreducible water saturation.

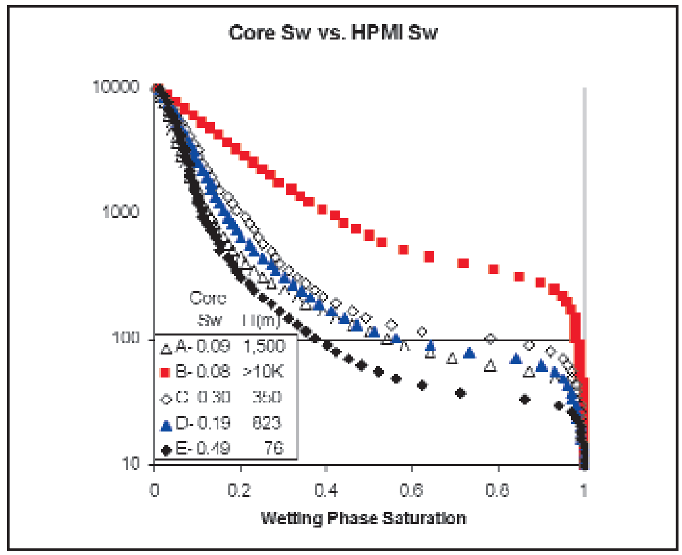

Figure 10. Semi-log plot of height above free water (dry gas) versus wetting phase saturation. All of these plugs are from the same core. The core SW combined with the capillary pressure data, would suggest widely varying gas column heights which is not the case.

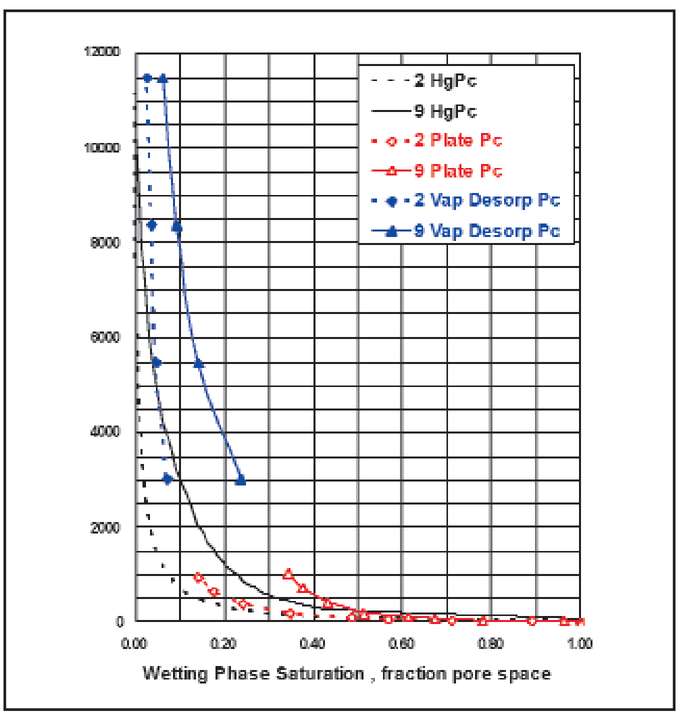

Figure 9. Cartesian plot comparing high pressure mercury injection capillary pressure to composite vapor desorption/high speed centrifuge data. (Data courtesy of Pat Lasswell, OMNI Laboratories).

A wide variation in potential column height is observed when capillary pressure data and core water saturation are combined in a recently acquired core (figure 10). Column height variations of 2 orders of magnitude are observed when deriving the potential column height using the HPMI data and the water saturations determined from the core. As a comparison, gas-column heights observed in similar rocks range from 300 to 1,000 ft (90 to 300 m) in low-permeability gas reservoirs in the Greater Green River Basin of Wyoming USA (Cluff , 2002) .

The wide variation in potential column height may not however be solely related to the problems associated with the capillary pressure or the core water saturation data. Simple extrapolations of capillary pressure data to hydrocarbon-column heights and saturations could be misleading in basins that have experienced considerable relative uplift and where gas migration and charge commenced before maximum burial was reached (Shanley et al, 2004).

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Saturation Expponent (*n*)

Differences in the Archie saturation exponent (*n*) can vary by 20 percent depending on rock type and analysis technique. Test apparatus configuration and duration can have a large effect on the determination of these factors. Current thinking is that these tests can take weeks/months instead of days to become stable.

Single point resistivity index (RI) tests are currently being conducted for a joint industry program for North American tight gas reservoirs. The steering committee for the program decided that single point RI tests were the appropriate protocol. Recent studies suggest that this may not be the case.

Laswell et al (2005) looked at the variability of n in a clean and a shaley sandstone (sample 32). This analysis demonstrates the variability seen in this type of data collection. Data was collected using both centrifuge and vapor desorption techniques. The combination of these analytical techniques allows for a wide saturation range for data collection.

There is variability seen in this data related to both the analytical technique and the shale content of the sample (figure 11).

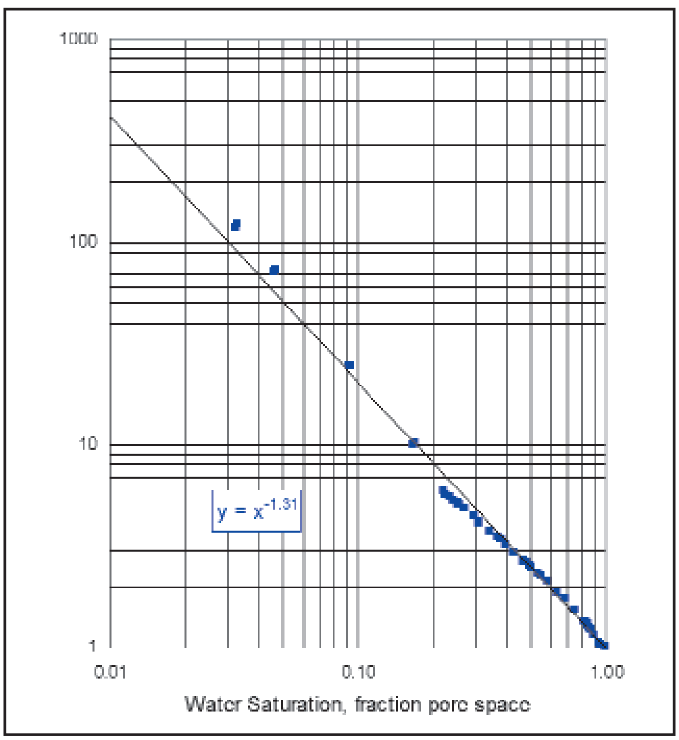

Figure 11. Resistivity Index and capillary pressure data for sample 32 (Laswell et al, 2005).

If only single data point was taken for this sample, what saturation value should be used? What is the variability in saturation exponent based on saturation?

Taken as individual analyses points, an incremental difference of 20 percent in n is observed depending on the final saturation chosen. The n value ranges from 1.58 to 1.17 for this rock. Given that most of our legacy information is single point RI, it is difficult to know how one could use single point RI measurements without a high degree of uncertainty.

Conclusions

The ability to understand and limit the sources of petrophysical uncertainty is vital as low permeability rocks are evaluated world wide. Low permeability rocks are believed to have 50 percent primary and 50 percent secondary porosity connected with slot like pores. This makes them particularly susceptible to the effects of overburden stress and variable water saturation.

Recently published analytical and proprietary core data were investigated in an attempt to identify areas of uncertainty. The following data types were reviewed; 1) porosity, 2) permeability, 3) relative permeability, 4) formation water resistivity, 5) water saturation from core, 6) capillary pressure, and 7) saturation exponent.

Porosity measurements should be conducted at reservoir stress conditions. Porosity is retained at 95 percent of the unstressed values for many of the samples analyzed. Legacy data can be used with a fairly high degree of confidence. The accuracy of logging tools is an area that needs investigation.

Permeability needs to be measured at reservoir stress conditions. Legacy data for permeabilities less than 0.01md will be biased high by some multiple dependent upon the rocks. Legacy data at ambient conditions will also be biased high and could be off by an order of magnitude if permeabilites are less than 0.01md.

Relative permeability is highly variable depending on differential saturations and fluid properties. A 30 percent difference in recoverable gas can be modeled using the variability in the test data set.

Formation water resistivities are very difficult to determine in low permeability rocks. With low pore volume and related water saturation determination uncertainty, water salinities ranged a few orders of magnitude for the well presented.

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Low Permeability Gas Reservoirs

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Differences of 5 to 10 percent in irreducible water saturations resulted comparing the same samples using HPMI and centrifuge/vapor desorption. These differences will affect gas in place and gas column height assessments.

Differences of 20 percent in Archie saturation exponent (n) are seen on the same sample. Care should be taken in using single point resistivity index analyses especially in shaley sandstones.

Could these uncertainties explain the poor correlation that generally occurs between predictions of low-permeability reservoir behavior based on rock-catalog solutions vs. estimates of reservoir performance based on production logging (e.g., Al-Qarni et al., 2001)?

It remains to be determined how to use the enormous volumes of legacy data given these uncertainties.

Will the prudent evaluation of low permeability rocks worldwide require the ability to understand and limit these and other sources of petrophysical uncertainty, or is the current level of uncertainty acceptable? If the uncertainty level is unacceptable, how much improvement can be gained?

Do these rocks behave like "Archie" rocks, or is there some other approach that should be used? In his 1941 paper, Archie stated; "It should be remembered that the equations given are not precise and represent only approximate relationships. It is believed, however, that under favorable conditions their application falls within useful limits of accuracy". What are the "favorable conditions" and "useful limits of accuracy" in low permeability rocks?

Issues remain with petrophysical lab measurements and their application to subsurface characterization in low permeability reservoirs. The industry needs to understand the uncertainty inherent in the measurements used and work to reduce them or at least make all parties aware of the uncertainty.

Acknowledgements

The authors would like to express our thanks to the management of BP Americas Inc. for their continued support and permission to publish this paper. We would also like to thank Pat Laswell at OMNI laboratories Inc. for data and discussions of laboratory procedures and uncertainties. Thanks to Core Lab Inc. in Houston for their discussions on specific laboratory protocols. We would personally like to thank Keith Shanley, Bob Cluff and Alan Byrnes for discussion and/or use of their data. Thanks to Bob Cluff, Mike Webster and Cliff Black for their time and suggestions during editing. Finally, we would like to thank our partners for allowing us to release the data presented herein.

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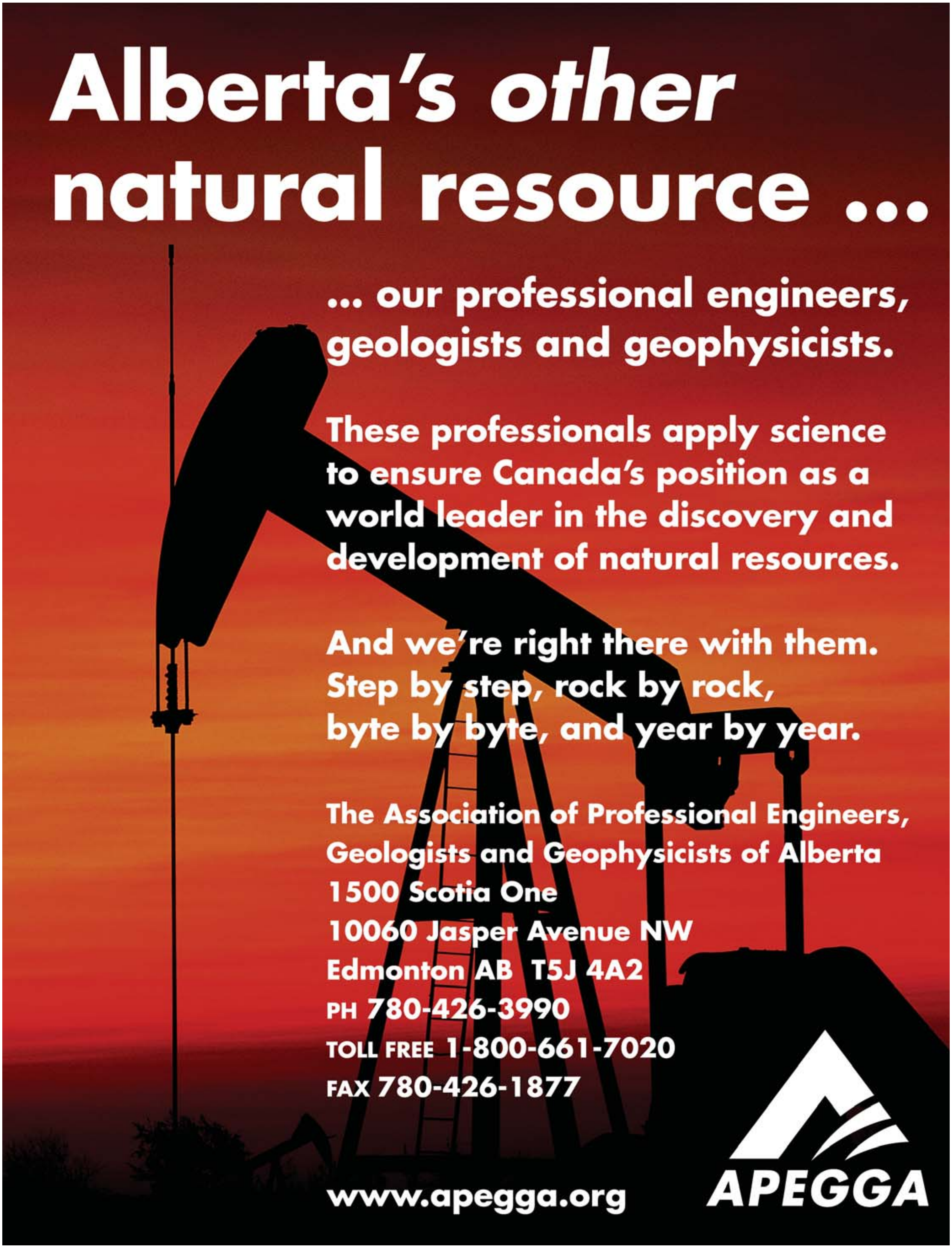
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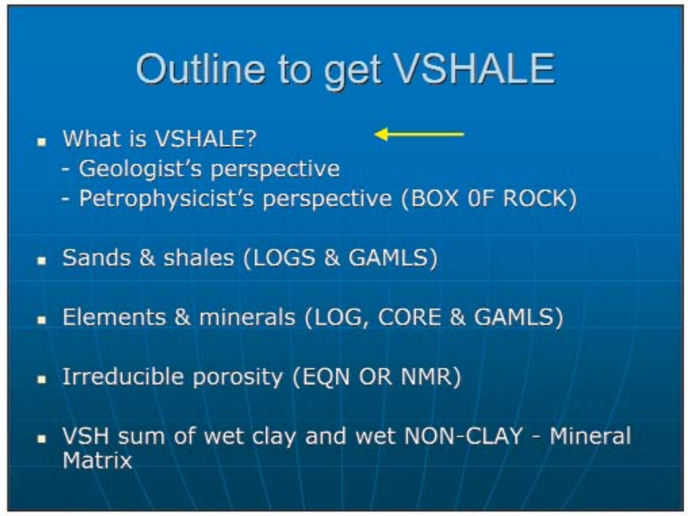
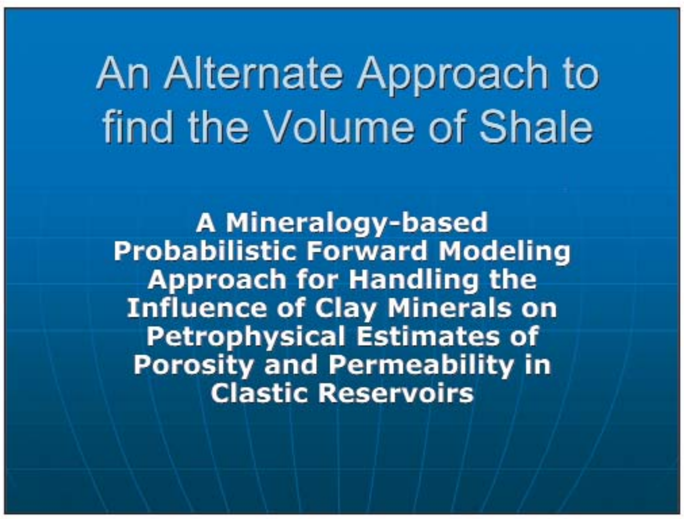
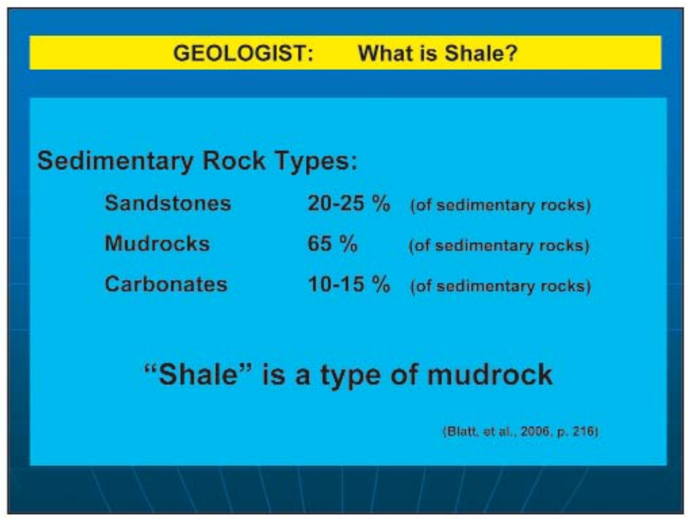
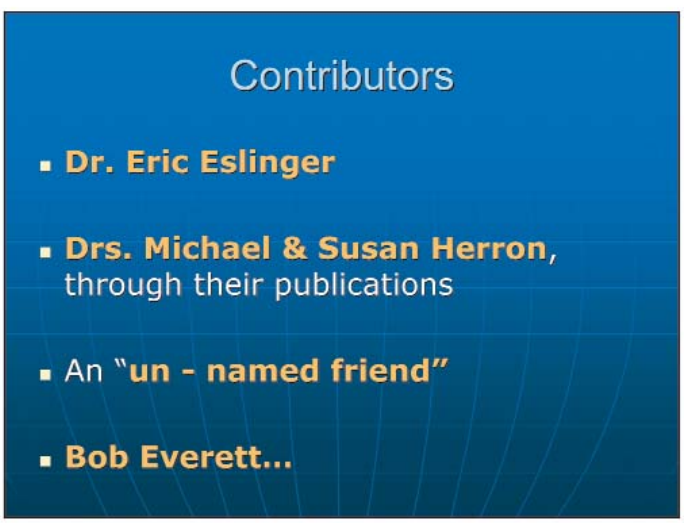
Tech Corner – An Alternative Approach to Find VSHALE - Handling the Influence of Clay Minerals on Estimates of Porosity and Permeability

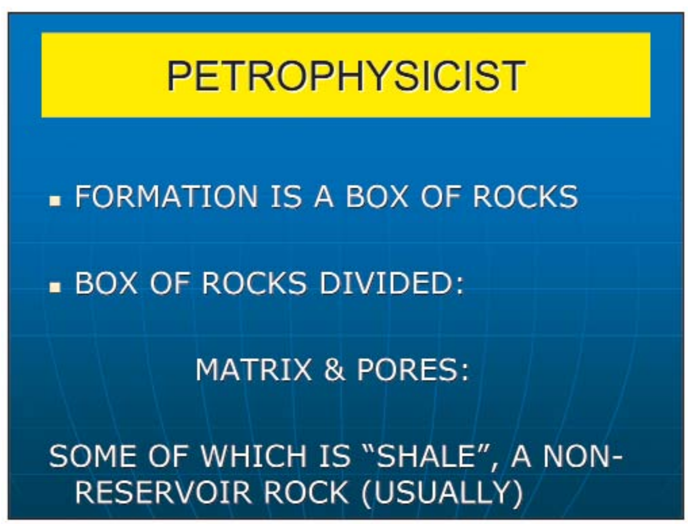
In this issue under the section of the Tech Corner is has been put to us as the editor's of the InSite that perhaps we could try to incorporate some of what the luncheons have given us as far as the presentation is concerned but not in the form of a paper. This may allow the readers who unfortunately were not able to attend the luncheon last month the ability to capture our presenters slides. Thanks very much to those who have given us their feedback already and we welcome anymore that you may have on this topic. We are also in the process of perhaps trying to make the luncheon slides available on the website with the authors permission and will do our best to make that possible in the future. Many Thanks to Bob for his contribution both at the luncheon discussion as well as to allow us to publish these. Hope you enjoy.











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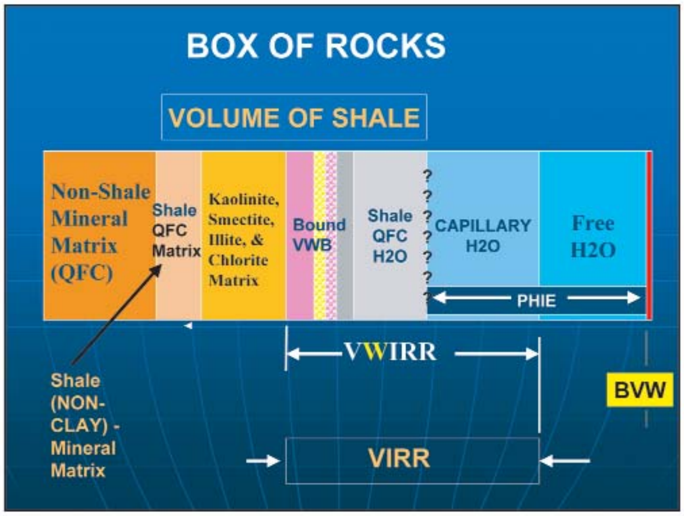

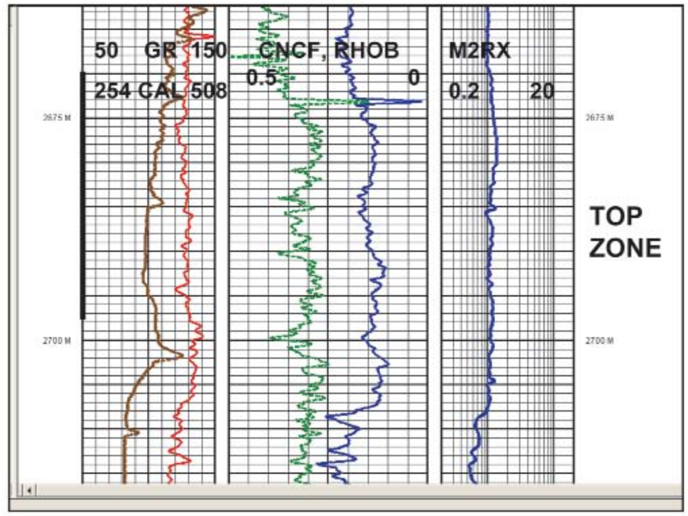

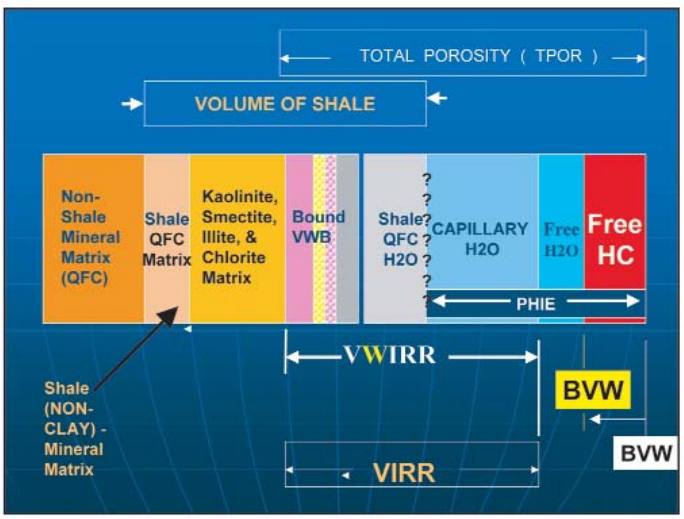

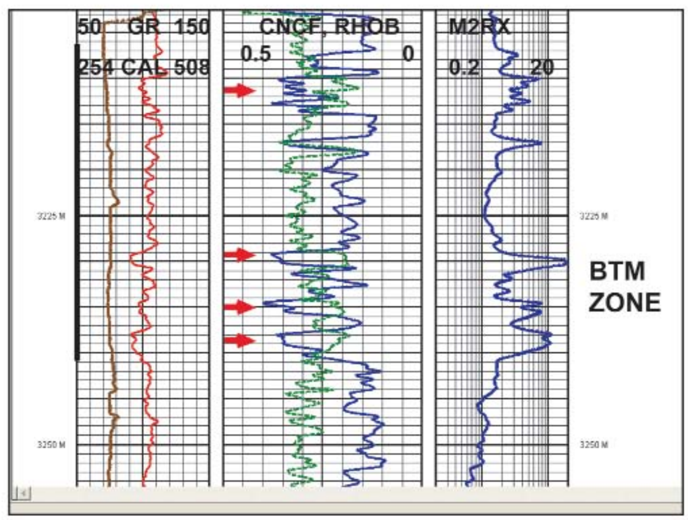

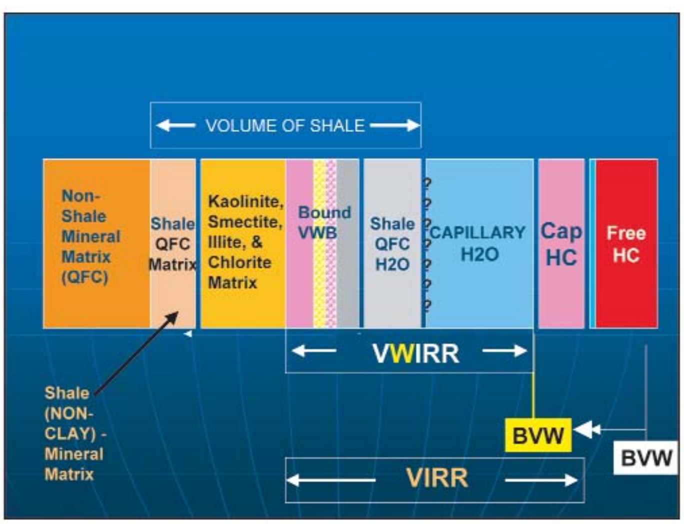

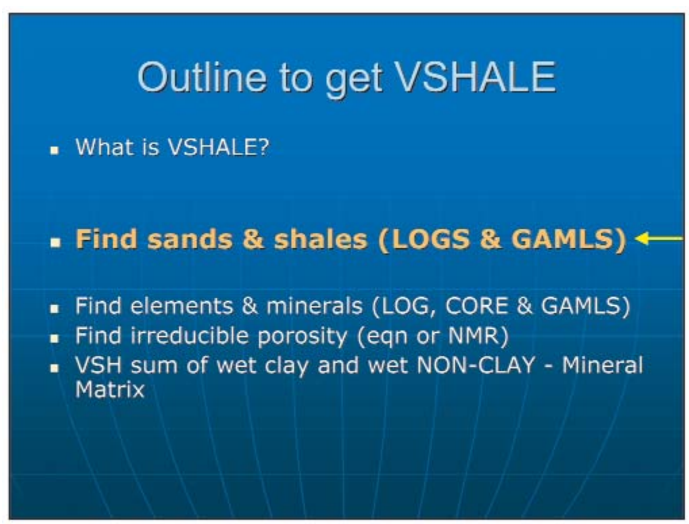

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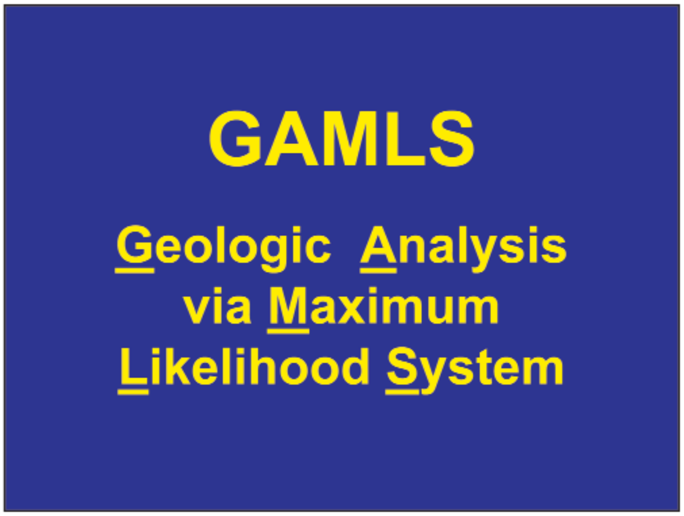

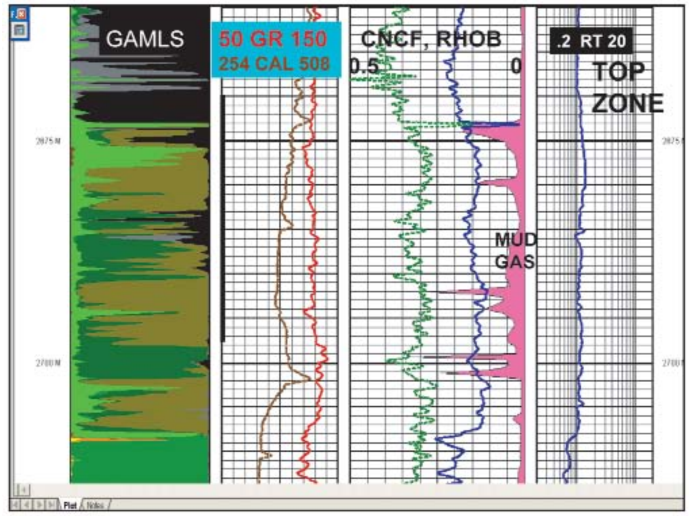

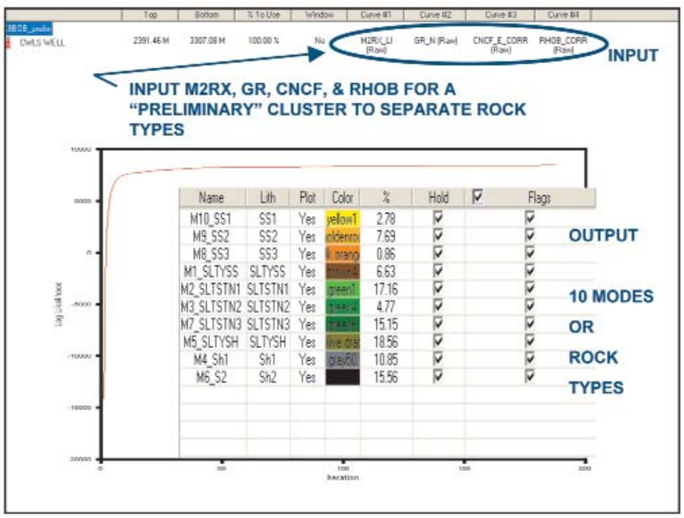

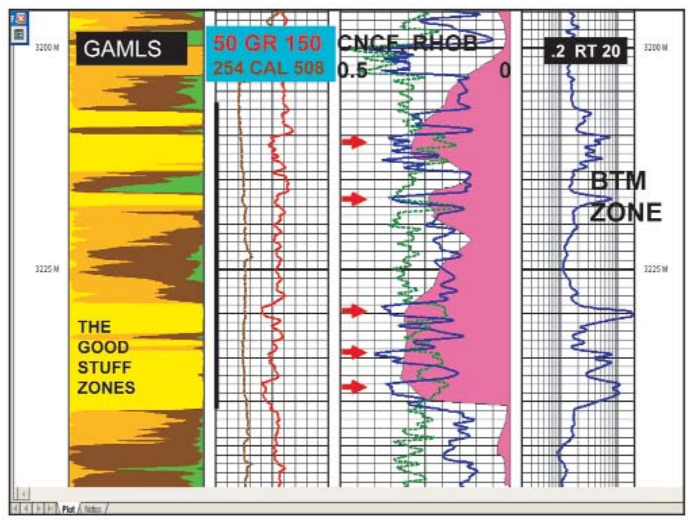

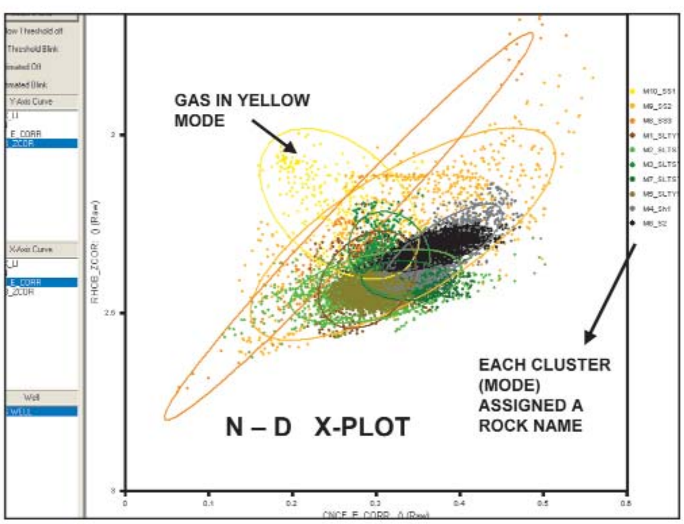

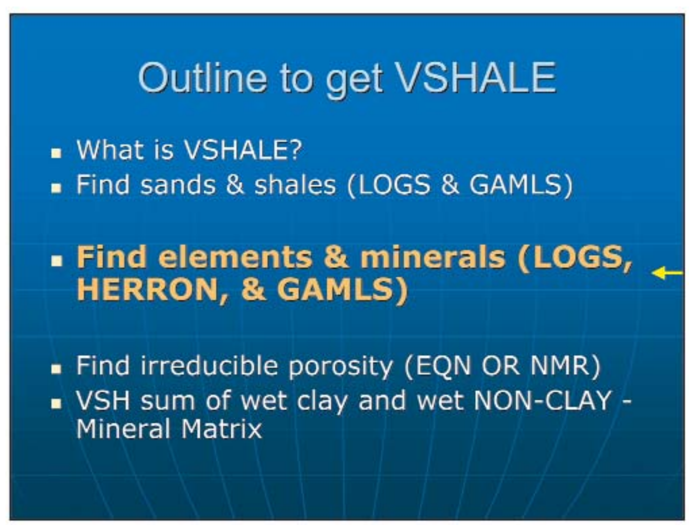

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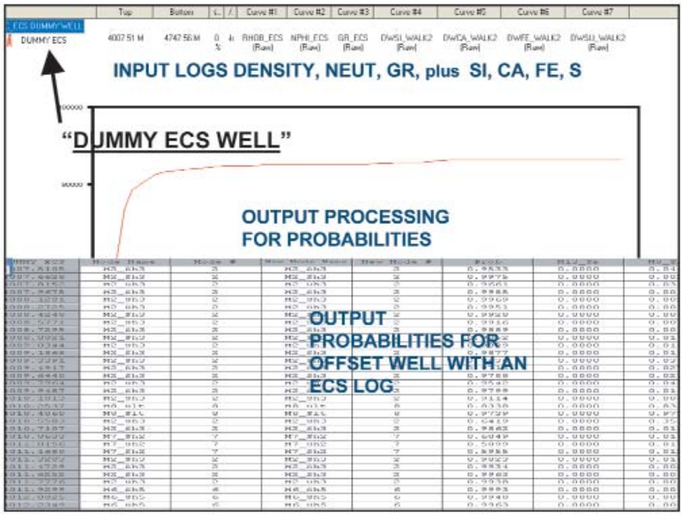
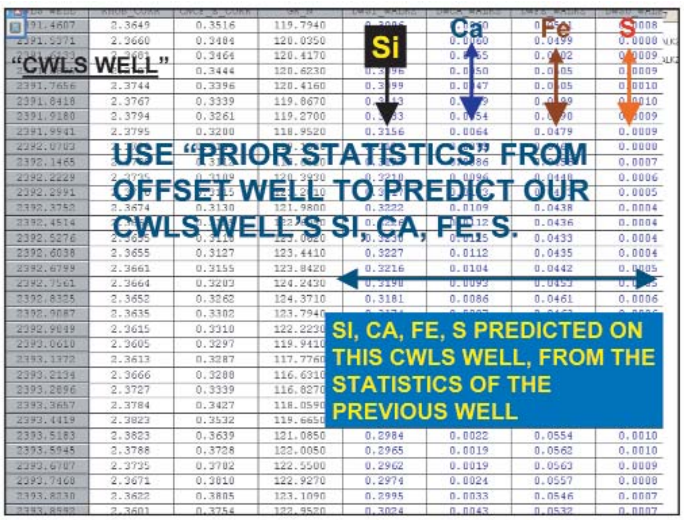


Herron's Equations

RHOG = 2.620 + 0.0490*WSI + 0.2274*WCA + 1.993*WFE + 1.1193*WS

TPOR = (RHOG - RHOB) / (RHOG - RHOF)



Herron's Equations for CLAY

WCLAY =
1.91 *(1 – 2.139*WSI – 2.497*WCA - 1.99*WFE)

VCLAY = WCLAY * (1-TPOR) * RHOG / RHOi

Where RHOi is 2780 kgm/m3 for illite, or 3420 for chlorite…

Minerals - WCLAY…

- "REAL TIME PETROPHYSICAL ANALYSIS IN SILICICLASTICS FROM THE INTEGRATION OF SPECTROSCOPY AND TRIPLE-COMBO LOGGING," **HERRON & HERRON** ET AL, 2002, **SPE 77631**, SAN ANTONIO TX 29-SEPT-2 OCTOBER 2002

Herron's Equations

Neutron Matrix (NMA) =

0.408 - 0.889*WSI - 1.014*WCA - 0.257*WFE + 0.675*WS

PHIN_MAN = (NMA - PHIN) / (NMA - NF)

Continued on page 41…

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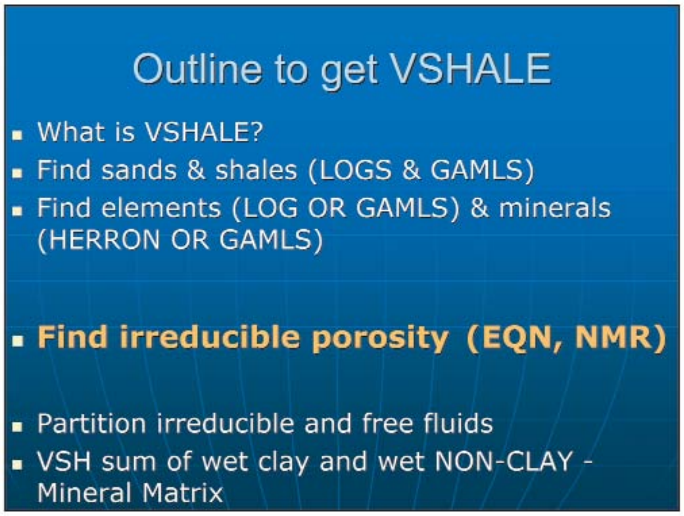

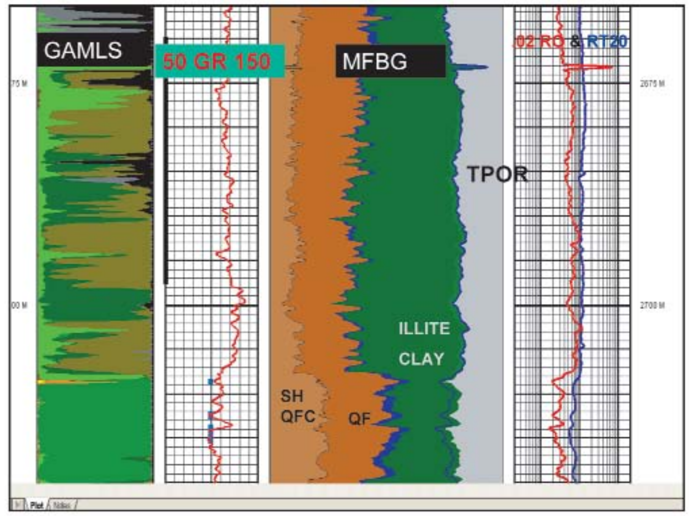

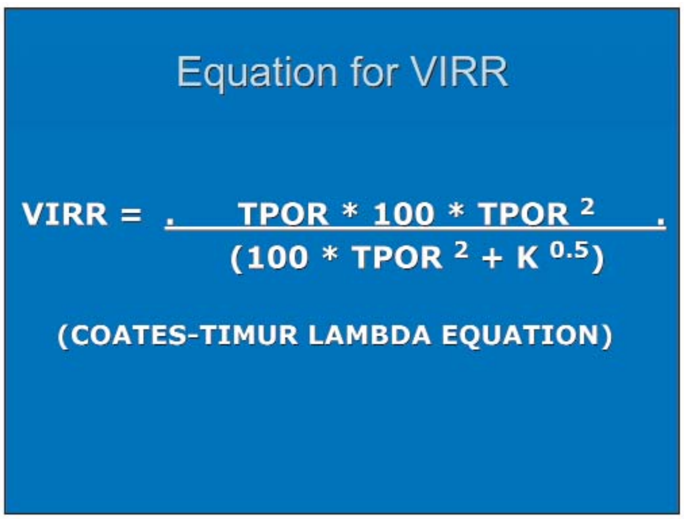

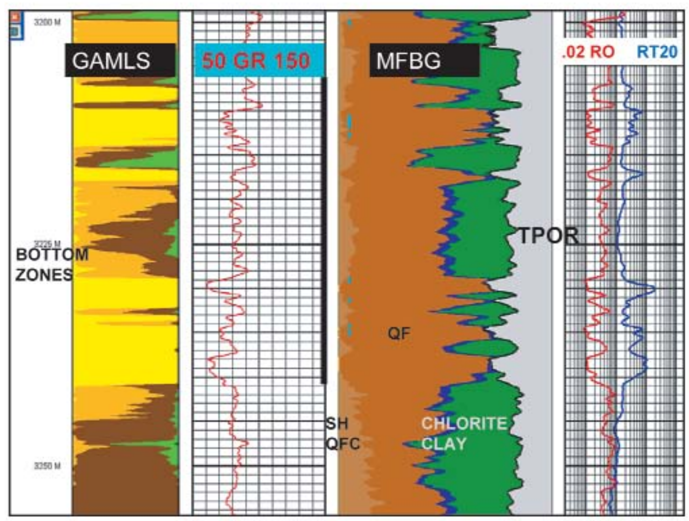

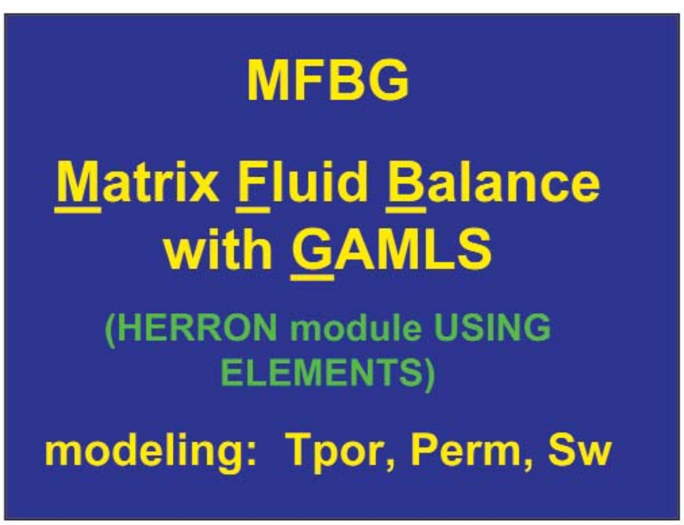

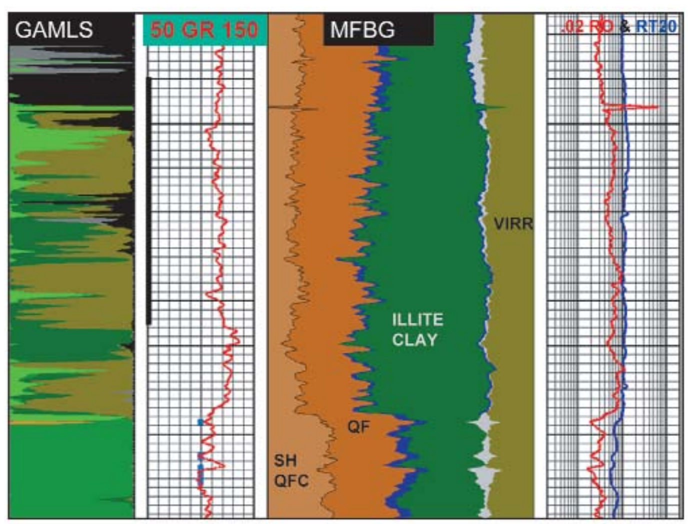

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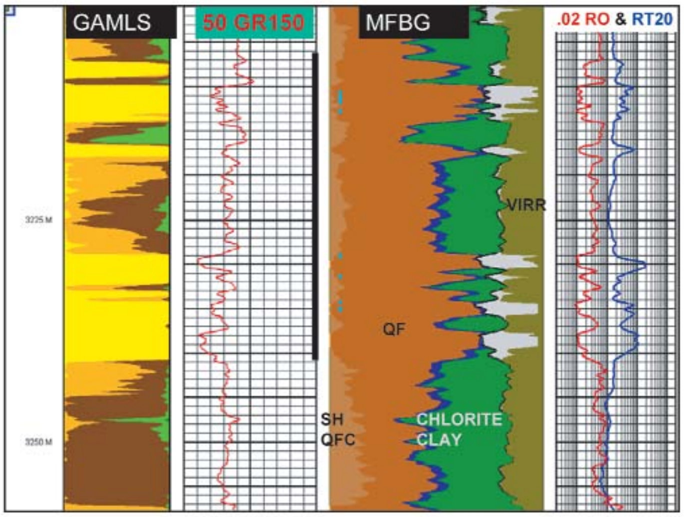

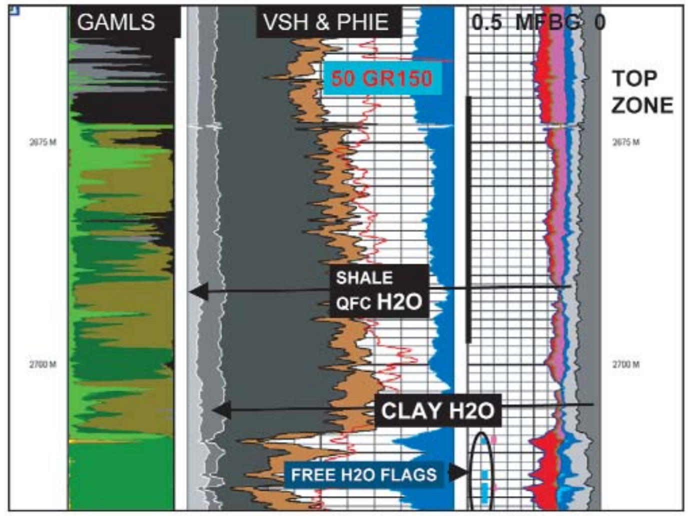

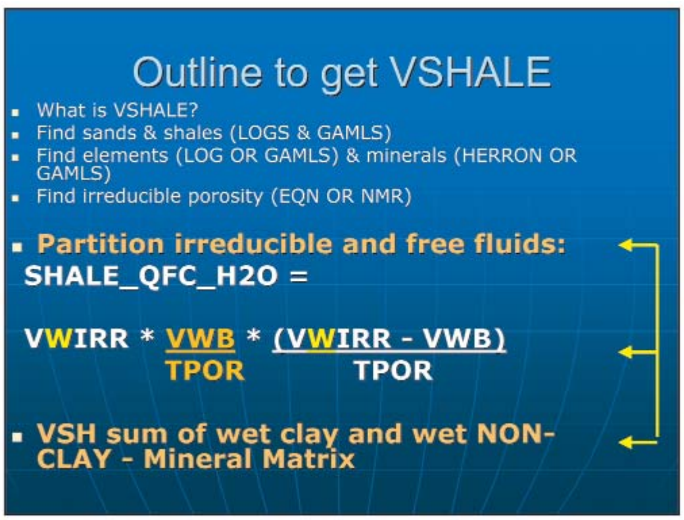

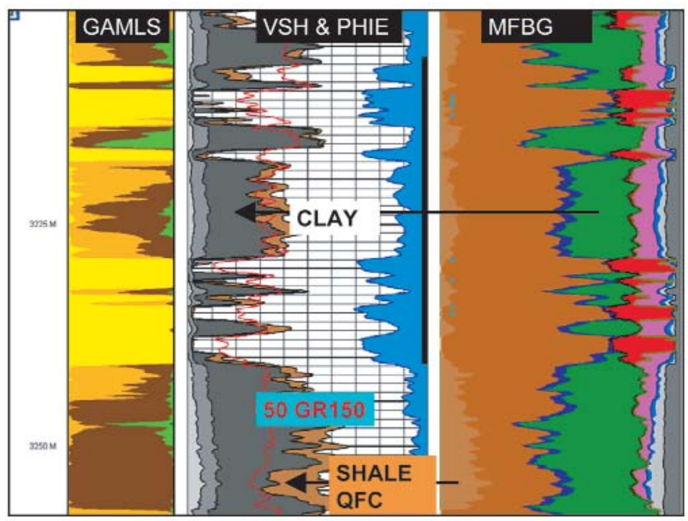

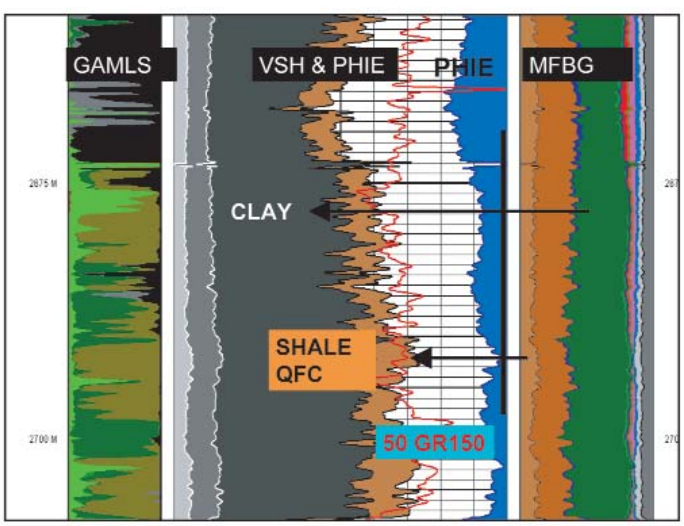

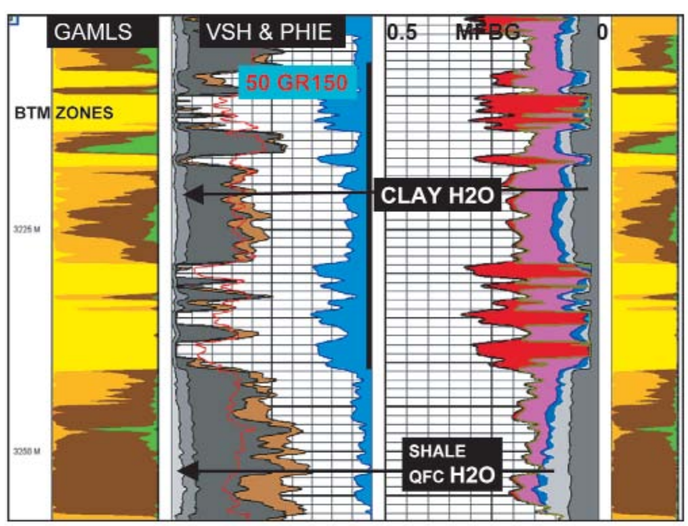

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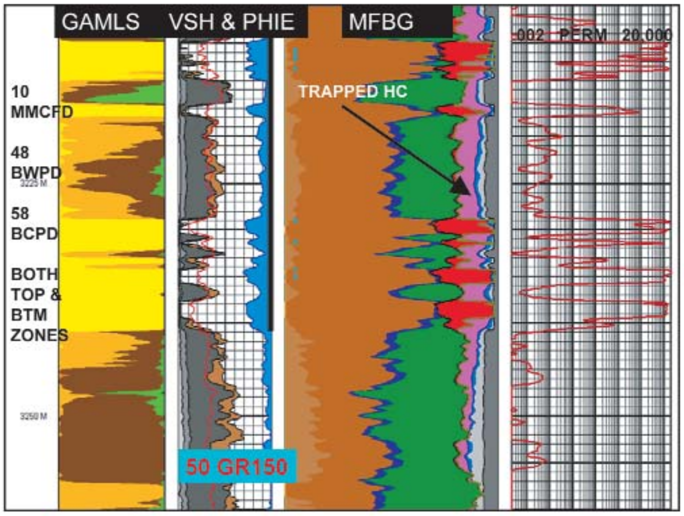


SUMMARY IRREDUCIBLE WATER

Total irreducible water is:

VWIRR=MIN(BVW, VIRR_HERRON) &

VWIRR= VWirr_SH + CAP + VWB

Outline to get VSHALE

- What is VSHALE?
- Find sands & shales (LOGS & GAMLS)
- Find elements (LOG OR GAMLS)
  & minerals (HERRON OR GAMLS)
- Find irreducible porosity (HERRON)
  & Partition irreducible and free fluids
- VSH sum of wet clay and wet NON-CLAY - Mineral Matrix (in shale)
- **& AS A BONUS, THE INTERPRETATION SAYS FRACTURING IS REQUIRED**

H2O IN NON-CLAY of SHALE

- VWirr_SH = amt of total irred water minus capillary and bound H2O

ASSUME

VWIRR_SH ~

VWIRR * VWB/TPOR * (VWIRR-VWB)/TPOR

CONCLUSION VSH FROM MINERALOGY

- **REQUIRES IRREDUCIBLE POROSITY**
- **IF NO CORE, NEED ELEMENTS**
- **WHY NOT TRY IT?**
- **TUUM EST ☺**

MINERALS IN NON-CLAY SHALE

- SAME AS MINERALS IN MATRIX
- VOLUME OF MINERALS IN NON-CLAY SHALE IS BASED ON RATIO OF WATER IN SHALE TO TOTAL POROSITY
- VQFC_SH =
  VQFC * VWIRR_SH / TPOR

Continued on page 44…

Tech Corner … *continued from page 43*

H20 IN CAPILLARIES

- CAP_H20 =

  VWIRR – VWIRR_SH - VWB

MINERALS IN CAPILLARIES

- SAME AS MINERALS IN MATRIX
- VOLUME OF MINERALS IN CAPILLARIES IS BASED ON RATIO OF WATER IN CAPILLARIES TO TOTAL POROSITY
- VQFC_CAP =

  VQFC * CAP_H2O / TPOR

GEOLOGIST: What is Shale?

How to regard shales in terms of log analysis?

1. Log analyst definition different from geologist's definition
2. Log analyst's "shale" includes all mudrocks
3. Mineralogy of a log analyst's "shale" not easy to quantify
4. Volume of shale not easy to quantify
5. Vshale includes minerals other than clay minerals

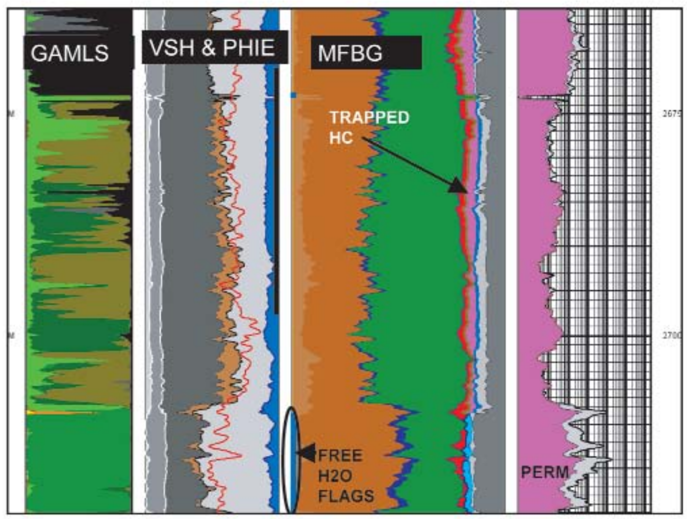
   (Vshale not the same as Vclay)

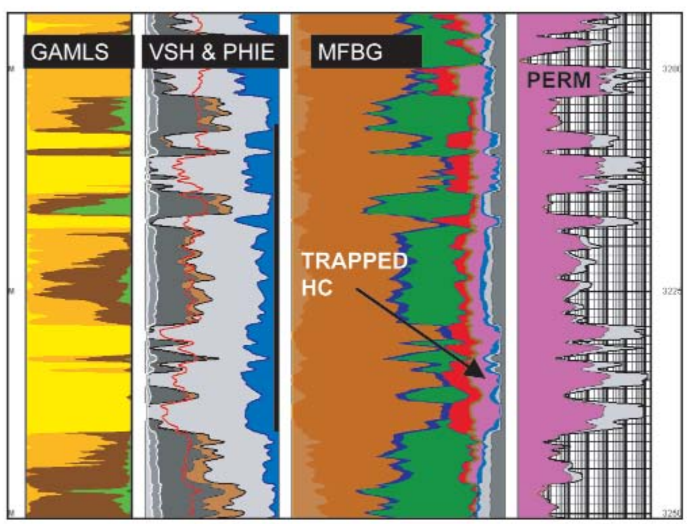
GEOLOGIST: What is Shale?

Mineralogy of Mudrocks (~ "shales")?

Fissile	Non-fissile	Major Minerals		
silt-shale	siltstone	↑	↑	
mud-shale	mudstone	qtz	fsp	cly
clay-shale	claystone			↓

(Blatt, et al., 2006, p. 271)





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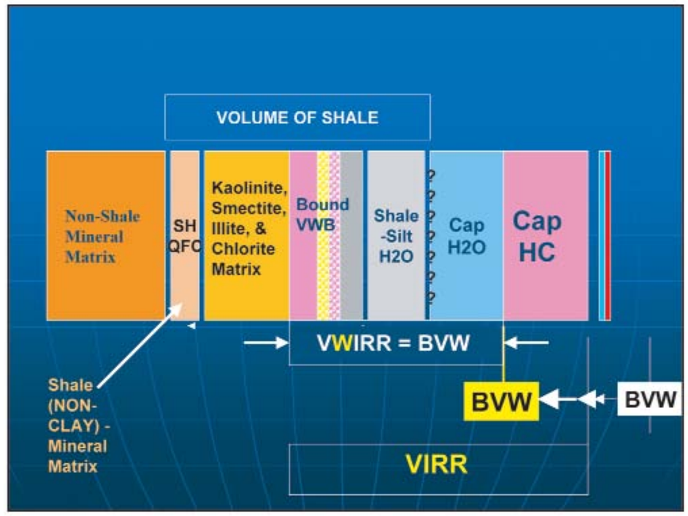

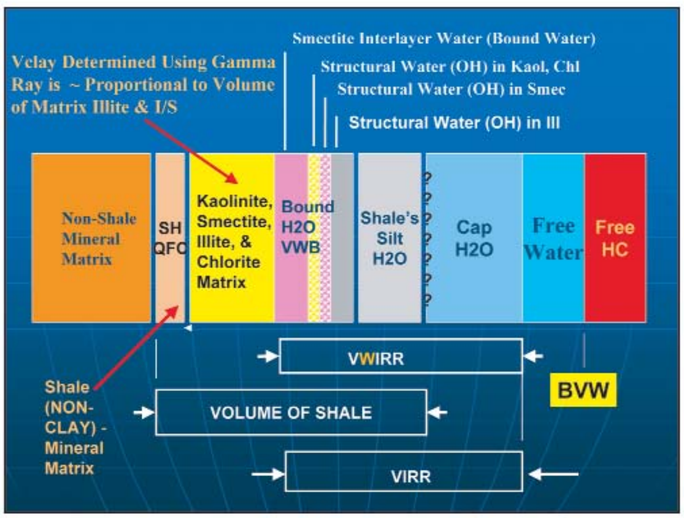

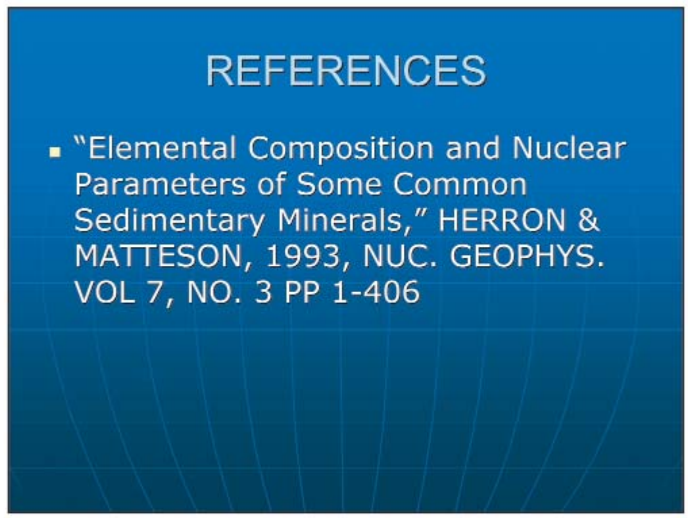

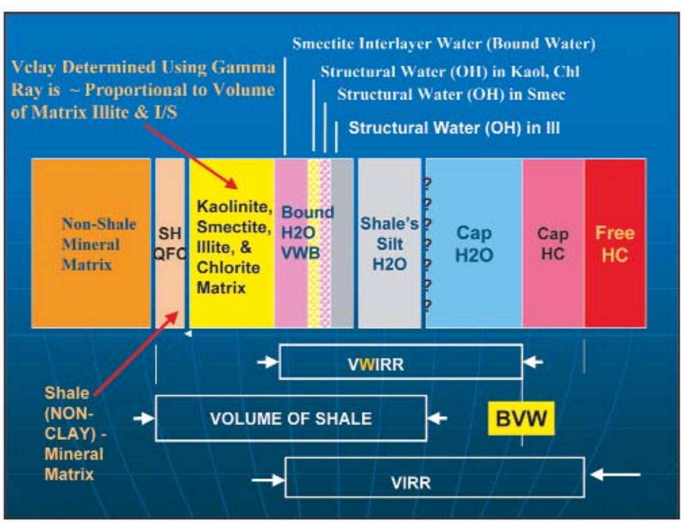

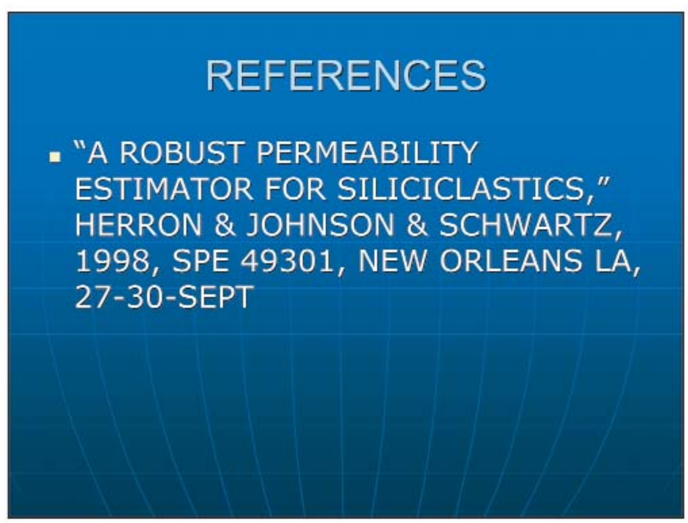

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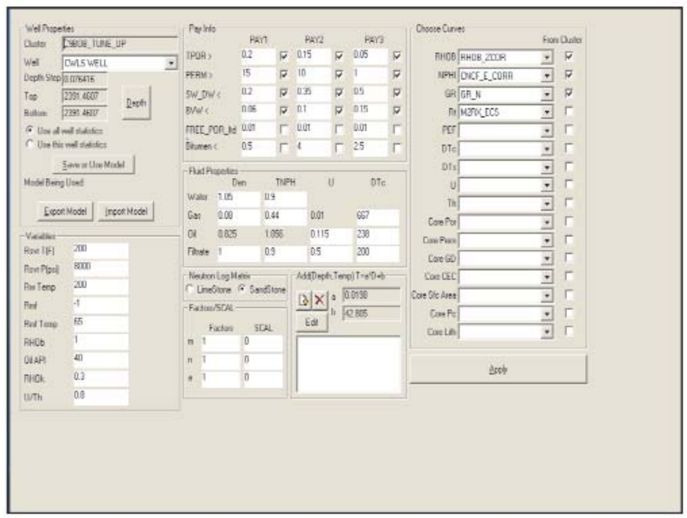
REFERENCES

- "ESTIMATING THE INTRINSIC PERMEABILITY OF CLASTIC SEDIMENTS FROM GEOCHEMICAL DATA," HERRON, 1987, SPWLA TRANS PAPER HH 1-23

	Density	So	CEC	K2O	U	Th	G
Qtz_c	2.65	0.11	0.00	0.00	0.10	0.00	0.
Qtz_m	2.65	0.22	0.00	0.00	0.10	0.00	0.
Qtz_f	2.65	0.43	0.00	0.00	0.10	0.00	0.
Qtz_slt	2.65	1.20	0.00	0.00	0.10	0.00	0.
Ksp	2.57	0.30	0.00	12.30	0.40	1.10	170
Nsp	2.61	0.30	0.00	0.60	0.00	0.00	7.
Csp	2.76	0.30	0.00	0.00	0.10	0.00	0.
Msv	2.84	2.00	0.00	9.40	0.00	0.70	127
Bio	3.22	2.00	0.00	8.70	0.70	1.50	127
Cal	2.71	0.60	0.00	0.00	1.40	0.00	11.
Cal_2	2.71	0.60	0.00	0.00	1.40	0.00	11.
Dol	2.87	0.50	0.00	0.00	0.90	0.10	7.
Dol_2	2.87	0.50	0.00	0.00	0.90	0.10	7.
Ank	2.99	2.00	0.00	0.00	0.00	0.00	0.
Kao	2.62	23.00	2.00	0.10	3.20	19.00	102
Smc	2.63	46.00	100.00	0.70	7.10	26.00	170
IS_lo	2.68	64.00	75.00	2.30	6.40	20.00	162
IS_hi	2.73	82.00	50.00	3.90	5.50	16.00	160
Ill	2.78	101.00	25.00	5.40	4.80	12.00	158
Gln	2.85	101.00	25.00	7.20	5.40	3.00	150
Chl	3.42	23.00	2.00	1.20	4.20	16.00	113
Pyr	5.02	0.30	0.00	0.00	0.00	0.00	0.
Sid	3.96	2.00	0.00	0.00	0.50	0.40	5.
Hem	5.26	2.00	0.00	0.00	0.00	0.00	0.
Bar	4.50	0.10	0.00	0.00	0.00	0.00	0.
Anh	2.98	0.10	0.00	0.00	0.90	0.10	7.
Gyp	2.32	0.10	0.00	0.00	0.00	0.00	0.

REFERENCES

- "QUANTITATIVE LITHOLOGY: AN APPLICATION FOR OPEN AND CASED HOLE SPECTROSCOPY," HERRON & HERRON, 1996, 37TH SPWLA TRANS PAPER E, NEW ORLEANS LA, JUNE 16-19



REFERENCES

- "APPLICATION OF NUCLEAR SPECTROSCOPY LOGS TO THE DERIVATION OF FORMATION MATRIX DENSITY," HERRON & HERRON, 2000, 41ST SPWLA TRANS PAPER JJ, DALLAS TX, JUNE 4-7

	Ss1	Ss2	Ss3	SltySs	Sltstn1	Sltstn2	Sl
Qtz_c	0.00	0.00	0.00	0.00	0.00	0.00	0
Qtz_m	0.00	0.00	0.00	0.00	0.00	0.00	0
Qtz_f	54.00	34.00	35.00	29.00	0.00	0.00	0
Qtz_slt	0.00	0.00	0.00	30.00	40.00	38.00	3
Ksp	11.00	4.00	7.00	3.00	5.00	5.00	2
Nsp	15.00	5.00	11.00	9.00	8.00	7.00	3
Csp	0.00	0.00	0.00	0.00	0.00	0.00	0
Msv	0.00	0.00	0.00	0.00	0.00	0.00	0
Bio	0.00	0.00	0.00	0.00	0.00	0.00	0
Cal	0.00	0.00	0.00	0.00	0.00	4.00	0
Cal_2	0.00	0.00	0.00	0.00	0.00	0.00	0
Dol	6.00	7.00	0.00	8.00	0.00	4.00	0
Dol_2	0.00	0.00	0.00	0.00	0.00	0.00	0
Ank	0.00	0.00	0.00	0.00	0.00	4.00	0
Kao	0.00	0.00	0.00	0.00	0.00	0.00	0
Smc	0.00	0.00	0.00	0.00	0.00	0.00	0
IS_lo	0.00	0.00	0.00	0.00	0.00	0.00	0
IS_hi	0.00	0.00	0.00	0.00	5.00	0.00	0
Ill	14.00	50.00	45.00	20.00	40.00	38.00	6
Gln	0.00	0.00	0.00	0.00	0.00	0.00	0
Chl	0.00	0.00	0.00	0.00	0.00	0.00	0
Pyr	0.00	0.00	2.00	0.00	2.00	0.00	2
Sid	0.00	0.00	0.00	1.00	0.00	0.00	0
Hem	0.00	0.00	0.00	0.00	0.00	0.00	0

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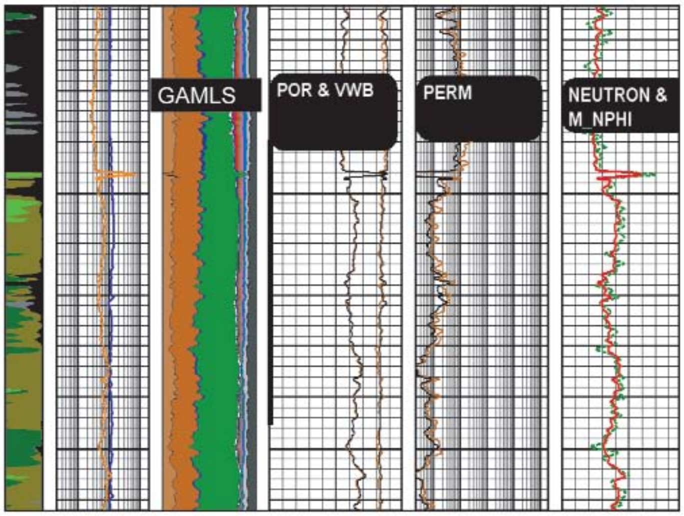
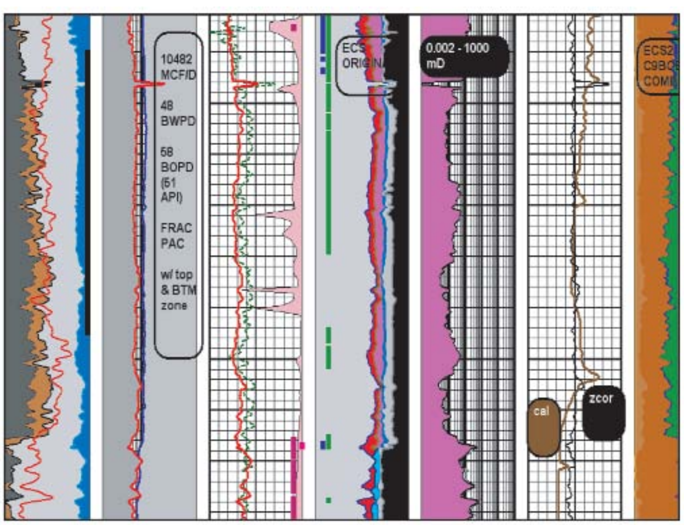


Lith-Use	M10_SS1	M9_SS2	M8_SS3	M1_SLTYSS	M2_SLTSTN1	M3_SLTSTN2	M7_SL
Qtz_c	0.00	0.00	0.00	0.00	0.00	0.00	0.
Qtz_m	49.00	25.00	0.00	10.00	0.00	0.00	0.
Qtz_f	10.00	19.00	9.00	25.00	0.00	20.00	0.
Qtz_slt	0.00	0.00	30.00	0.00	24.00	29.00	18
Ksp	5.00	4.00	3.00	7.00	5.00	5.00	2.
Nsp	11.00	5.00	9.00	11.00	8.00	7.00	3.
Csp	0.00	0.00	0.00	0.00	0.00	0.00	0.
Msv	0.00	0.00	0.00	0.00	0.00	0.00	0.
Bio	0.00	0.00	0.00	0.00	0.00	0.00	0.
Cal	0.00	0.00	0.00	0.00	0.00	0.00	4.
Cal_2	0.00	0.00	0.00	0.00	0.00	0.00	0.
Dol	10.00	7.00	8.00	0.00	15.00	0.00	10
Dol_2	0.00	0.00	0.00	0.00	0.00	0.00	0.
Ank	0.00	0.00	0.00	0.00	0.00	0.00	0.
Kao	0.00	10.00	0.00	10.00	10.00	0.00	10
Smc	0.00	0.00	0.00	0.00	0.00	0.00	0.
IS_lo	0.00	0.00	0.00	0.00	0.00	29.00	0.
IS_hi	0.00	10.00	10.00	10.00	5.00	10.00	10
Ill	15.00	20.00	30.00	25.00	30.00	0.00	37
Gln	0.00	0.00	0.00	0.00	0.00	0.00	0.
Chl	0.00	0.00	0.00	0.00	0.00	0.00	0.
Pyr	0.00	0.00	0.00	2.00	0.00	0.00	3.
Sid	0.00	0.00	1.00	0.00	3.00	0.00	3.
Hem	0.00	0.00	0.00	0.00	0.00	0.00	0.
Bar	0.00	0.00	0.00	0.00	0.00	0.00	0.
Anh	0.00	0.00	0.00	0.00	0.00	0.00	0.



About the Author

Robert (Bob) V. Everett, BASc in Mechanical Engineering (University of British Columbia, 1964, Vancouver, British Columbia) is a Petrophysical engineer with over 41 years of USA, Canadian and international experience. He began at Schlumberger of Canada, starting as a field engineer. He worked at Schlumberger-Doll Research in Shaly Sands Interpretation that has led to the development of Schlumbergerís Elemental Capture Spectroscopy Service (ECS). Bob specializes in unusual Petrophysical interpretation, where innovation and forward thinking are keys to successful economic evaluations.

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TOPIC: Geomechanical Wellbore Imaging: Key to Managing the Asset Life Cycle

SPEAKER: Colleen Barton Ph.D.,Vp, Senior Technical Advisor, Co-Founder GeoMechanics International Inc

ABSTRACT:

A field-specific geomechanical model serves as a platform for dramatically reducing costs and increasing production over the life of a field. With a geomechanical model, exploration risk associated with fault seal breach can be minimized. Drilling engineers can provide recommendations for efficient well design and placement and to reduce adverse events such as stuck pipe and lost circulation, completions can be optimized to extend the productive life of wells and to avoid or manage solids production. The effects of depletion and injection can be predicted to enable optimal exploitation that avoids excessive reservoir damage, casing collapse, and hazards related to leakage of produced or injected fluids. Quantitative risk analysis (QRA) then can be used to propagate the uncertainties in geomechanical model parameters through the analysis and to determine an optimal solution to better manage the controllable drilling and production parameters that present the primary risks to field development

The essential contribution of wellbore image technologies to these exploration and production challenges are illustrated through recent case studies that apply both conventional and advanced imaging technologies to the detection, access and recovery of hydrocarbons. Future reservoir development and management practice will demand an increased use of imaging techniques to ensure successful production in risky drilling environments, reduce the costs associated with drilling, and increase the economic lifetime of mature reservoirs.

BIOGRAPHY:

Colleen Barton Ph.D., VP, Senior Technical Advisor, Co-Founder GeoMechanics International Inc.: Senior geomechanical analyst in the areas of wellbore stability, reservoir permeability and fault seal integrity applied to oil and gas reservoirs. She advises GMI's worldwide consulting staff on unique technical problem and provides technical guidance to the Company's software product development. Dr. Barton is considered an industry expert in wellbore image analysis technologies.

Before completing her Ph.D. at Stanford in 1988 in reservoir geomechanics, she spent two years as a research scientist at the Massachusetts Institute of Technology conducting research in wellbore sonic logging. She also had a four-year career in the field of geotechnical geophysics. From 1988 to 1996 Dr. Barton was at Stanford University developing techniques in in situ stress measurement and enhanced recovery from fractured reservoirs. GeoMechanics International was founded in 1996.

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

UPCOMING EVENTS

June 3 - 6, 2007
2007 SPWLA Annual Symposium
Austin, Texas

June 5, 2007
CSPG Technical Luncheon
Structural Style and Hydrocarbon Prospectivity in fold and thrust belts: a global review
Mark Cooper
Telus Convention Centre, Calgary, Alberta

June 7, 2007
CWLS Technical Luncheon
Geomechanical Wellbore Imaging:
Key to Managing the Asset Life Cycle
Colleen Barton, Ph.D.
Calgary, Alberta

June 19, 2007
CSPG Technical Luncheon
Good Help Isn't Hard to Find... It Feels Impossible
Heather Douglas
Telus Convention Centre, Calgary, Alberta

October 15-17, 2007
Gussow Geoscience Conference
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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.

For information on advertising in the InSite, please contact either of the publications co-chairs:

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Discounts on business card advertisement for members.

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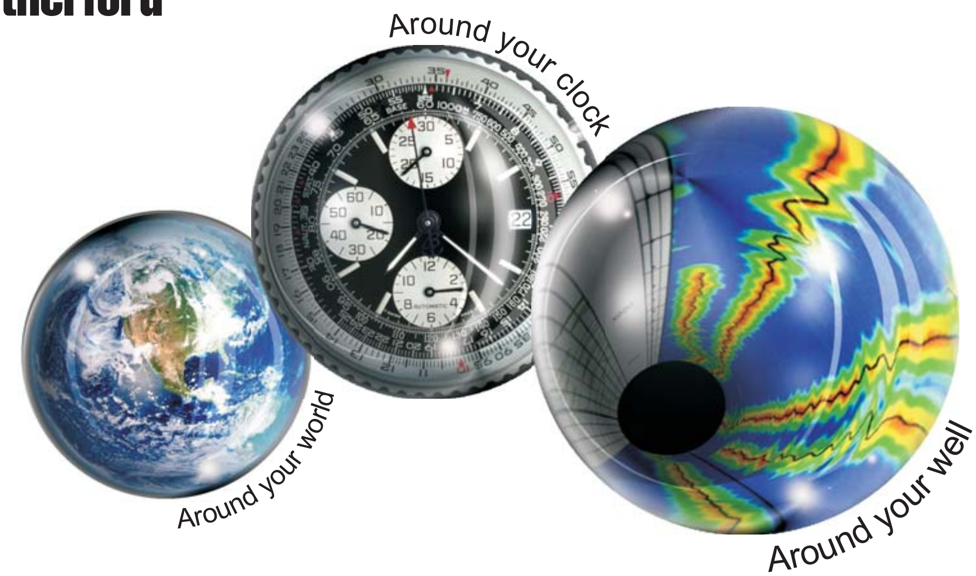

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