InSite

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A spectacular sunrise 24 km west of Estevan, SE Saskatchewan in the Tableland field, mid February, 2005. Photo courtesy Ben Urlwin.

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

The 2005 - 2006 CWLS Executive:

Front row from left to right: Carley Gyori, Richard Bishop, John Nieto, Ken Faurschou, Dion Lobreau
Back row from left to right: Jeff Levack, Ben Urlwin, Gary Drebit, Robert Bercha

President's Message

Spring is here! With it, a couple of months respite to get caught up on evaluations, reports and new project work. According to the logging companies, the past year is on record the busiest ever, with over 21,500 wells and more than 23,000,000 metres drilled, 10% higher than the previous high! Interestingly, the annual ritual of 'break-up' lasting from April to June, then drill like crazy for the winter months is becoming smeared. There's no doubt that ice bridges and road bans, sodden leases rightly restrict activity in spring and summer, but it seems that operators are returning to 'the drill' where ever they are able. This load balancing is good – keeps everyone active, if not busy, year round!

Before moving on to current CWLS affairs, I'd like to give a short report on the joint CWLS-SPWLA conference in Kananaskis. The conference was, based on all feedback that I've had, a resounding success! There were 96 attendees staying in Kananaskis, fully a third of these were from Calgary, thanks to the membership for great support!

The recipe for the conference was good – great location, (new snow for the skiers!), excellent support from the Delta Lodge staff, and a well balanced mix of unconventional reservoir topics. Our guest speaker, Dave Russum gave an excellent after-dinner lecture on "The Importance of Unconventional Gas in North America". On the technical front, fractured reservoirs, shale gas and tight sand reservoirs were all covered equally, each with excellent speakers and willing participants in the break-out sessions. There were many key questions and issues in each reservoir type, some were highlighted and a few even solved, not bad for a three and a half day workshop!

Briefly, issues that rose to the top of the pile were:

Tight Gas reservoirs – Uncertainty in gas-in-place determination and invasion of drilling fluids into these low permeability rocks. Completion techniques in tight gas reservoirs.

Shale Gas reservoirs – Minimum data requirements for evaluation of gas shales, interpretation of resistivity response in gas shales, various completion techniques in gas shales.

Fractured Reservoirs – Accuracy of porosity and water saturation measurements in fractured reservoirs, optimization of logging programs in fractured reservoirs, interwell distribution of fractures – with scaling issues.

Moving to current affairs. The new committee is working well together on all fronts, we meet regularly to plan events....and on this, we should be on course for a terrific 50th Anniversary lunch on September 7th. . We are planning to hand out a special commemorative gift to each lunch attendee – you must be present to get one of these gifts, once they are gone, they are gone – no more will be made!

There are BIG developments underway on the website. We are always looking at how to increase the value of your membership of the CWLS. In the pipe, there's an all new GIS based Rw catalogue, Special Core analysis database, on-line, searchable CWLS transactions and Knowledge transfer (community of practice) site. Have a technical question? Log in and ask the collective CWLS experts for their opinion… watch this space!

As ever, if anyone has any questions, ideas or suggestions, please don't hesitate to come forward at the lunch meetings, call or email me, Cheers!

John Nieto, CWLS President.
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CWLS President, John Nieto presenting SPWLA President, John Quirein with a warm souvenir Canadian Well Logging Society blanket (throw) at Kananaskis in March. (right) Vicki King SPWLA Executive Director receiving her CWLS blanket.

As the Winch Turns: Shell Albercan Govenlock # 1

It has been quite a while so some of the details are a little fuzzy. Geologic retrieved the well ticket for me and it seems to agree with my memories.

My first well log was on Shell Albercan Govenlock # 1: (02-07-001-28W3M) in the southwest corner of Saskatchewan across Willow Creek about a mile from the Canada Customs Station. The well was about 2000 feet deep when I arrived in early November, 1951 (US Thanksgiving) and I was the junior man on a three man Core Laboratories wellsite sample logging crew. Ray Gould was in charge, with Terry Adamson completing the team. Ray and Terry shared a housekeeping suite at the Shamrock Motel in Havre, Montana, 40 paved miles to the south, which they drove daily.

It was during this job that, just south of Coutts/ Sweetgrass, I saw my first Burma Shave signs:

HERE LIES STUBBORN O'DAY
DIED DEFENDING HIS RIGHT OF WAY
RIGHT, DEAD RIGHT AS HE SPED ALONG
COULDN'T BE DEADER
IF HE'D BEEN DEAD WRONG
BURMA SHAVE

Driving east from Great Falls we had passed several billboards:

"WHEN IN HAVRE – STAY AT THE
SHAMROCK MOTEL

RECOMMENDED BY CLYDE R. THOMAS".

The menu in the Shamrock restaurant said "owner Clyde R. Thomas".

Govenlock, Saskatchewan, was 15 or 20 gravel miles north of location, and had a garage, a post office, a tiny general store and several other buildings. My wife and I had a trailer on the lease and usually drove to Havre across the border for groceries, clearing Canadian Customs at the border then reporting to U.S. Customs in Havre when we got there.

The Govenlock well was operated by Shell, with Bill Weaver on location as the drilling foreman, and Art Rupp the wellsite geologist.

The well ticket says "Contractor unknown", however, I am pretty certain that Lloydminster Petroleum was the contractor. Lloydminster Petroleum had successfully drilled innumerable shallow wells in the Lloyd area and wanted to get into deeper well drilling. Lloyd had agreed to buy the triple drilling rig from Albercan provided it could drill to a depth of 6000 feet.

Albercan had repatriated the rig from Venezuela. There were four English diesel motors, three on the substructure and a never used spare by the lease fence. A full time mechanic tried to keep the motors running by welding shut the auxiliary oil coolers (definitely unnecessary in a Saskatchewan winter), and keeping a water hose running into the leaking radiators. Drilling continued as long as any two motors were OK. When they got down to one motor, they pulled out in low-low until another motor was ready, then drilling recommenced. Slowly by today's standards (200 – 300 feet per day) we reached the Mississippian formations, when the cherty dolomites encountered wore out the hardest bits (W7R) in just a few feet and many hours. At this point we shortened our sample interval to five feet.

Then the clutch burnt out and the driller had to finish coming out of the hole slamming into gear without the clutch. This additional stress bent the drum. The line had to be unspooled. The drum was sent to Calgary to have the drum axle straightened, returned to the lease, reinstalled, re-spooled and drilling recommenced. During this time the clutch had also been repaired or replaced.

Sometime before or after the clutch problem, a rod on the mud pump went through the side of the pump. This blew the pop valve sending a jet of mud across the sump, knocking over the outhouse on the far side of the sump. Luckily nobody was in it. A replacement pump was found on an idle rig in Montana. The Texas crew had left (stating no reasonable crew would drill in -40 degrees.)

Eventually the English diesels were replaced with twin Jimmies, and drilling proceeded. As the well neared TD, and anticipating road bans, a Schlumberger truck and a shothole rig were brought on to location so that a seismic survey measuring oneway travel time could be run. This took longer than planned because spring had begun and the few feet of snow we had was already underlain by inches of slush. This triggered numerous shorts in the geo

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As the Winch Turns... *continued from page 4*

phone cables. As most of the shotholes were used up before all of the various travel times had been measured, a part of the seismic crew went back to Havre while the shothole crew drilled some more holes.

That night, Willow Creek flooded and went from a few inches deep to several feet, and from a few feet, to tens of feet wide. The crew rigged a line across the creek so individuals could be towed across on a kind of a breeches buoy. The road to Havre washed out in several places. After the flood subsided the trip to Havre could only be made by leap frogging from one vehicle to another that had been stranded in between washouts and walking across the washouts.

In recording the travel times the Schlumberger line hit a bridge and got snarled but was successfully pulled out and drilling recommenced. Because of road conditions, a replacement truck could not be brought in, so the Schlumberger crew of Steve Buckley and Tom Wilson made Schlumberger history by cutting out the snarled line and (with the manual) rewiring the sonde in the field (a job normally done in the shop). Rewiring was completed before the well reached TD.

Anticipating the thaw, I had parked my car on the other side of the creek before the flood and when the well was logged, I had a cat tow my trailer to Govenlock. The cat took the most direct route, which meant going through a few sloughs and thereby flooding the bottom foot of my trailer. I hitched a ride to my car and drove to my trailer. The water line was finally below the bed so we slept and headed for home in the morning. The washouts had been largely repaired but there was still a lot of the highway under water, and we saw numerous hoses pumping water from one side to the other. Heading west from Havre many stretches were lakes with highway edges marked by stakes. If you go slow you don't flood the motor. One stretch, water, water, only the stakes marking the edge of the pavement and the tops of barbwire fences showing it was not always a lake.

Dick McCreary

Photo taken beside the helideck on the Rowan Gorilla V, January 2004, while drilling the El Paso Mariner I-85 well, offshore Sable Island/Nova Scotia. The view is looking northwards towards the Venture Production Platform (operated by Petro-Canada). In between the Rowan Gorilla V and the Venture Platform is the western sand spit coming off of Sable Island. Photo Courtesy Ben Urlwin.

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Message from the Vice President

As we enter our 50th year as a society I thought it would be worthwhile looking back at why we have been successful as a society and how we are going to thrive in the next 50 years.

The CWLS was born when several petrophysical professionals realized that they needed a forum to share their ideas and knowledge for their own betterment and to move the profession forward. What resulted was the formation of the CWLS, one of the oldest societies in the world dedicated to log analysis and formation evaluation.

The CWLS is 100% based on volunteers for its existence. When you look back at the history of the CWLS executives and volunteers, it reads like a who's who of the Petrophysics community in Canada. We are a small community and to survive, the society must have all our members commit to volunteering to support the societies activities at some point in their career. For junior members volunteering is an excellent way to network with the senior members to build a network of contacts that can help with anything from finding an answer to a problem to finding the perfect job. For senior members it is a chance to help guide the society, network, mentor young members and repay their debt to the society.

The volunteers of CWLS have made many valuable contributions to the petrophysics community at large. The greatest influence may be the development of the LAS standard for the storage of digital log data, which has been adopted globally. The society is currently in discussions with the EUB to further develop capabilities of LAS and to develop a digital standard for log image storage. The other major initiative that the CWLS is known for is the Rw catalogue, the yellow binder in every Canadian Petrophysicist's library. The Rw catalogue was updated and brought into the digital age few years ago, it is now being moved to the web as an interactive map which will be available to members in the near future. The CWLS core database is also being updated and will be added to the interactive map.

How can you contribute? Volunteer to run for executive office and influence the present and future direction and management of the society. Volunteer to give a paper and share your knowledge, you will be contributing to one of the pillars of the society by sharing knowledge, you will receive valuable feedback from your peers and who knows, a future employer may be in the audience. A professional talk is also a great way to gain valuable points to maintain your APEGGA certification. Volunteer to act on a committee and influence an area of interest to you. Volunteer to help with a convention, it is a great way to meet new people in different disciplines and societies, expanding your professional contacts.

An unknown author wrote "Volunteer-not so you can build your resume, but so you can build yourself." You owe it to yourself to become involved.

Ken Faurschou

New Members

Jonathan Graham: Shell Canada Ltd.

David Dudas: Imperial Oil Resources

Lyle Hanch: Encana

Heath Pelletier: Veritas Geoservices

Francis Schloeder: Xavier Exploration

Craig Rice: Apache Canada Ltd.

Roupen Zakarian

Mike Murphy: Marauder East Coast

Eric Sacks: BP Canada

Brian Ard: Precision Wireline

Ryan Marshall: Precision Wireline

Kathy Hearn: Baker Atlas

Cary Reid: HydroCarbon Consulting

Shawn Carrol: Intergrated Production services

Ron Bray: Plenty Barrels Resources Inc

Carrie Dickinson: AEUB

Mike Carnley: Consultant Petrophysicist

Marc Purdon: Precision Energy Services

Yvonne Oliver: Precision Energy Services

Jim Jarvis: Anadarko Canada Corp.

Gordon Lee: Precision Energy Services

Samantha Etherington: Anadarko Canada Corp.

Dion R. Lobreau
CWLS Membership Chairman

Editor's Note

With break-up drawing to a close and rig counts starting to increase, companies are lined up for commencement of the summer drilling season, which, after seeing oil prices top CDN$62/bbl during the winter season, is likely to begin with a boom. Although having settled back down to the mid US$40 per barrel range, analysts are predicting similarly high (or even higher) oil prices for the coming year. This will no doubt keep the pressure on our oil and gas industry, making this winter even more hectic for services and equipment. This will likely be compounded by the recent announcement that the $7 billion dollar MacKenzie Valley pipeline project has been put on hold. This will bring added pressure to the Alberta and BC regions to produce more and more hydrocarbons to compensate. With reports of multiple new LNG import terminals coming on line in the next 5 years starting to surface, the pipeline project may very well be delayed further, or cancelled completely.

Another exciting facet of our industry is the expansive heavy oil deposits of central Alberta. With tens of billions of dollars of investment in heavy oil development planned by multiple companies over the next 10 years, Canada's export capacity will be increased significantly. Canada's heavy oil resource is estimated to contain upwards of 335 billion barrels* of oil. Using existing technology approximately 174 billion* barrels of this can be extracted (approximately 50% recovery factor). Recent investment in the Alberta heavy oil deposits by Chinese firms indicates a wider interest in this resource from the international community. At present, Canada exports approximately 1.6 billion barrels a day of crude oil to the United States, a number which is only going to increase as the US struggles to managed it's energy supply and demand. Heavy oil will also play a major role in increased exports for Canada not only to the US, but also potentially to countries such as China, which is growing at a pace that far outpaces its energy supply capabilities. If future plans, such as the suggested pipeline to the west coast, pan out, Canada may be exporting oil to China within the next 10 years.

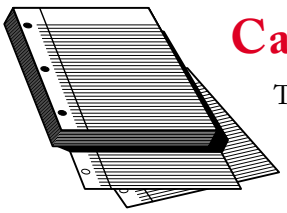
**Source: http://www.energy.gov.ab.ca/docs/oilsands/pdfs/FactSheet_OilSands.pdf*

As a added feature, this months InSite has a new column titled "Canadian Well Logging History". The column will be looking at the history and development of the CWLS as an organization within Canada. This month's column includes the first two press releases put out by the CWLS after its inception in August, 1955, and provides a quick glimpse of the roots of the CWLS, and the inspirations behind the organizations genesis.

In this InSite our first paper will be of significant interest to those involved in heavy oil. Dr. Andrew Chen's paper titled "Testing In Oil Sands" looks at running wireline conveyed formation testers in Alberta's oil sands formations. Our second paper is provided by Pat Laswell of Omni Laboratories and is titled "Electrical Property Determinations in Conjunction with Vapor Desorptions". Both these papers are informative and thought provoking. Finally, this issue's Tech Corner looks at NMR. A brief overview of the technology utilized for this tool, and its associated pitfalls, are provided in understandable terms.

Enjoy the InSite!

Robert Bercha
Ben Urlwin
CWLS Publications Co-Chairs



Call for Papers

The CWLS is always seeking materials for publication. We are seeking both full papers and short articles for the InSite Newsletter. Please share your knowledge and observations with the rest of the membership/petrophysical community. Contact publications co-chairs Ben Urlwin (ben@waveformenergy.com) at (403) 538-2185 or Robert Bercha (robert_bercha@anadarko.com) at (403) 231-0249.

Testing Oil Sands

Dr. A. Chen, AJM Petroleum Consultants

Synopsis:

This article addresses the difficulty of running wireline-conveyed, plunger style formation pressure tests in Alberta's oil sands formations. This paper will specifically discuss these issues:

1. Why probe-type pretests may not accurately measure true formation pressure.
2. What do typical wireline test responses look like, and how do we interpret them?
3. What are the possible practical solutions, if any?

Introduction

There are two great challenges in testing Alberta's oil sands: almost immobile bitumen and soft unconsolidated loose sands.

Canada's Oil Sands are comprised of expansive deposits of bitumen. Bitumen is best described as a thick, sticky form of crude oil, commonly so heavy and viscous that it will not flow unless heated or diluted with lighter hydrocarbons. Bitumen's in-situ viscosity can be as high as millions of centipoises, meaning that at room temperature, it is much like cold molasses.

Formations bearing this bitumen are typically loose, unconsolidated sands with Darcys, or even tens of Darcys, permeability. Typically, these rocks are extremely soft. As a result, conventional drill stem testing has not proved successful due to various operational and technical issues (i.e. tool/pressure gauge plugging and formation crushing).

Many unjustified perceptions exist when it comes to testing tar sands with wireline testers. These include:

- Oil sands formations can be successfully tested by using a single probe wireline tester.
- The permeability of oil sands formations is very high, so a wireline test chart should be good.
- Wireline testers are fast and cheap, satisfying the low operational budget principle in the Western Canada.

However serious realities must be confronted including:

- Although oil sands do have high permeabilities, it is primarily the mobility (k / μ), that determines the success of a test. In a tight gas sand scenario, permeability can be as low as 1~2 md, however, gas viscosity is in the order of 0.01 cp, giving a mobility of 100 ~ 200 md/cp. This is still quite a favorable threshold. In the oil sands scenario, the formation may have a permeability of 5 Darcys, but the bitumen viscosity is 2 million centipoises. Thus, the mobility is only 0.0025 md/cp. Literally the bitumen is not mobile.
- As a result of the immobility of bitumen, even if final shut-in buildup pressures are recorded from probe pretests and a pressure versus depth plot is constructed, it is very unlikely to exhibit a meaningful pressure gradient picture. In many cases, a water gradient is derived. This is a result of the in-situ bitumen density being within the same range as the drilling fluid filtrate (usually gel-chem water), thus making it impossible to differentiate between the two.
- The near-wellbore formation is heavily "supercharged". This does not necessarily involve any lateral invasion – causing supercharged formation pressure in the traditional sense. Instead, vertical drainage is the predominant mechanism, and if vertical permeability is poor (due to the presence of clay/shale), localized formation pressurization can occur. As a result, the final shut-in pressure at the end a WFT pretest buildup, even if stabilized, is not equivalent to the formation pressure (bitumen oil phase pore pressure).
- Similar to a DST test, traditional probe-based wireline testers may not be able to acquire the necessary formation pressure and fluid information.

Measurement Principles of Wireline Testers

Although the wireline formation tester (WFT) measurement principle in oil sands is no different from that with a normal reservoir, the flow mechanism might be quite different, resulting in a totally different outcome. This forces us to question the validity of these probe-based wireline test pressures.

Drilling fluid invasion physics must be studied here to demonstrate the WFT flow process. Figure 1 shows two pictures of mud invasion (or filtration) process in a normal formation and in a tar sand formation. In a normal formation, mud invasion occurs as a result of drilling bit circulation, known as the dynamic invasion, and/or the pressure overbalance, known as the static invasion. A mud cake (or filter cake) usually develops during these invasion mechanisms. In Figure 1(a), the formation pressure is P_f, the mud hydrostatic pressure is Pm, and the thickness of mud cake is t_m. The invaded filtrate penetrates into the formation, and the penetration distance is r_i (where the pressure is equalized to the formation pressure P_i). During this

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process, lateral invasion usually occurs when invaded filtrates displace either hydrocarbon or formation brine into the formation.

If formation permeability is low, a pressure gradient profile along the radial distance into the reservoir is formed. There is usually a sharp pressure loss profile across the mud filter cake (assume that the mud filter cake is of good quality). Low formation permeability prohibits any quick equalization of pressure in the invaded formation. As a result, the WFT measured pressure, P_{sf}, is usually higher than the true formation pressure, P_f, and thus we refer to this phenomenon as supercharging.

If formation permeability is high, a good quality mud cake usually stops or minimizes filtrate invasion. Meanwhile, the pressure behind the mud cake usually bleeds off quickly. As a result, the WFT probe measured pressure, P_{sf}, is equalized to the formation pressure.

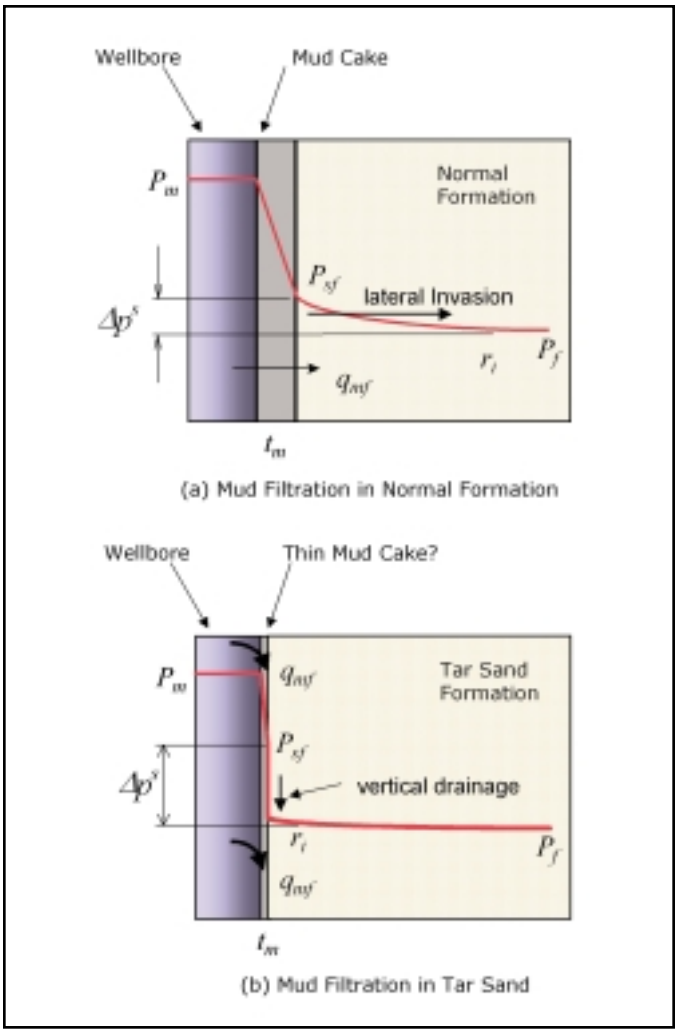

Figure 1. Mud Filtration/Invasion in Normal and Tar Sand Formations

Mud cakes in low permeability rocks, due to lateral invasion, are usually hard and thick, and in high permeability rocks are soft and thin. Invasion profile and mud filter cake can be detected by caliper and array-induction resistivity logs. In tar sands it has been found mud cakes are not often well built, and no deep invasions have been observed. This is not surprising because the tar sand fluid mobility is extremely low, usually less than 0.01 md/cp in any circumstance. What this implies is that the bitumen will not yield to mud hydrostatic pressure and accept invasion.

Figure 1(b) illustrates the most likely scenario for a wireline formation test in oil sands. Because of bitumen's immobility the filtrate must drain downward along the sandface which is "coated" by a very thin layer of mud cake. The thin mud cake in this situation will not be hard and of super low permeability.

When a wireline tester is set for pretest, the packer squeeze can be very high as the probe-pad is pushed against the mudcake/sandface (Figures 2-6). This is because there is no thick mud cake to squeeze. After the pretest chamber is opened, usually no fluid enters the tool, causing the pressure to drop to zero, a typical tight formation response behavior (Figure 5).

In some cases the vertical drainage does not happen efficiently. The pressures across the thin mud cake might be retained due to either poor vertical permeability as a result of clay/shale presence or due to mud fluid short circuit. So the WFT measured pressure, P_{sf}, is still high. In this case, a supercharged pressure is still recorded at the end of a pretest (Figures 3-4).

Typical Charts from Probe-based Wireline Testers

Commonly there are four types of wireline tester strip charts which summarize the probe-based pressure pretest behaviors: *seemingly normal, slow buildup, buildup toward mud hydrostatic, and dry test*.

Seemingly Normal Tests: In most cases, do not provide accurate formation pressure measurements (Figure 2). Generally they are "infected" by the supercharge effect seen in oil sands situations. There is still a possibility that this kind of test may hit on the right spot where the formation fluid is connate water. However, chances are that the flow-back fluids are locally charged mud filtrate with elevated on-wellbore pressures. Therefore the final shut-in pressure will have a very high probability of being "elevated" or supercharged. In general, it is impossible to quantify the value of this effect.

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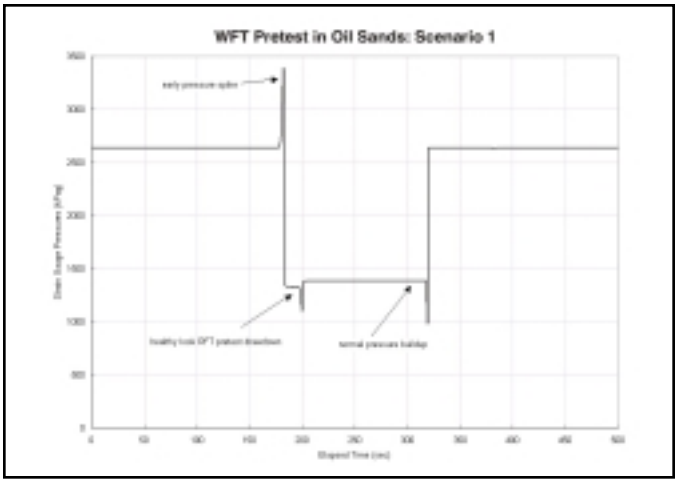

Figure 2. WFT Pretest in Oil Sands with Seemingly Normal Pretest

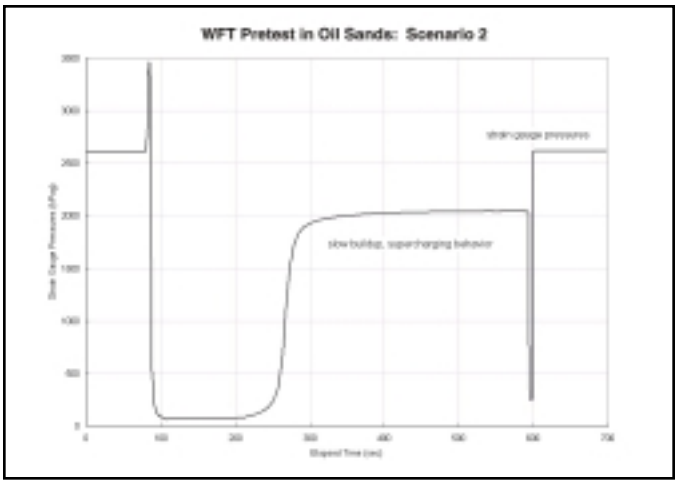

Figure 3. WFT Test in Oil Sands with Slow Buildup

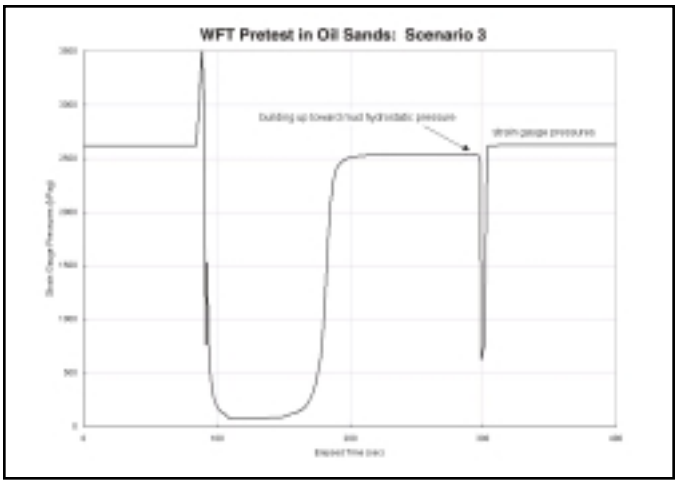

Figure 4. WFT Test in Oil Sands with Buildup Toward Mud Pressures

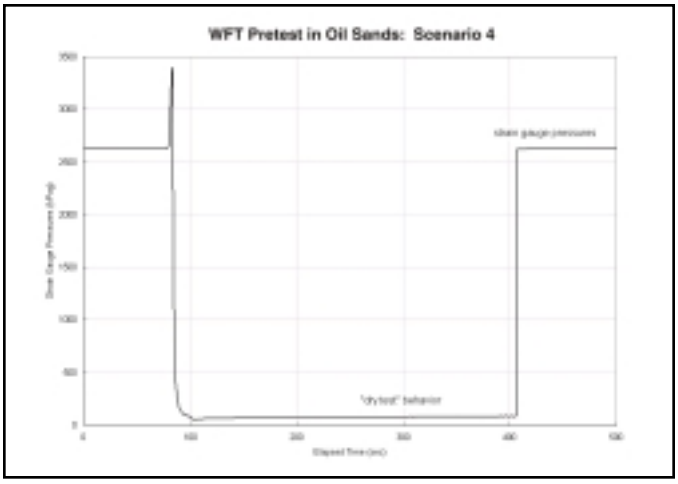

Figure 5. WFT Pretest in Oil Sands with Dry Test Behavior

Slow Buildup Tests: Usually show that the final shut-in pressures are stabilizing somewhere between the mud hydrostatic pressure and no pressure (Figure 3).

Buildup Toward Mud Hydrostatic: Are the tests that occur often because the mud filter cake is not built well. This causes the "short circuit" of mud pressure along the sandface to the probe-head (Figure 4).

Dry Tests: Reveal the very nature of utilizing a probe type wireline tester in the oil sands environment (Figure 5).

If a larger volume flow is exercised during the test (by opening a large sampler or by turning on the downhole pump for extended flow), the response is either: 1) the pressure drops to

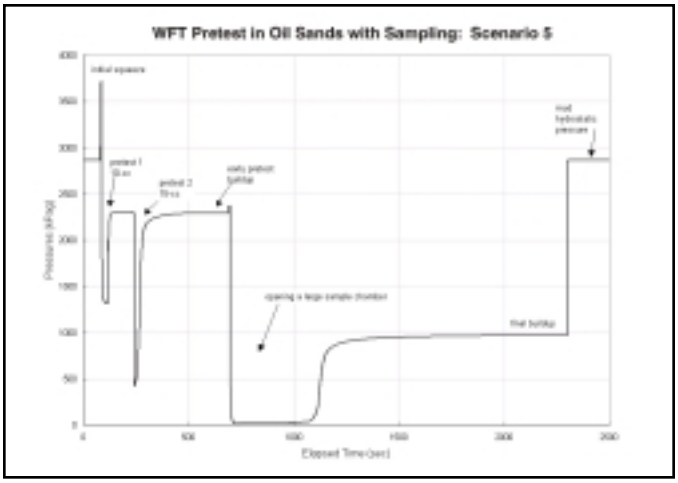

Figure 6. WFT Test in Oil Sands with Pretests & Sampling Test

Continued on page 12...

Testing Oil Sands... *continued from page 11*

zero, or 2) the buildup pressure never returns to the final shut-in pressure on the pretest.

In the test shown in Figure 6, two short pretests were conducted, seemingly repeating the final shut-in pressure. Once a large sample bottle was opened, the pressure did not build up to the two pretest values or achieve stabilization. This test only confirms that the final shut-in pressures from the two early pretests were not really the formation pressure at this depth. It does not confirm that the final pressure at the end of sampling was the correct formation pressure.

Modeling a WFT pretest flow and buildup is no easy task. This is due to the fact that commonly used flow equations are no longer applicable.

Pressure Versus Depth Plot

Not many valid pressures can be acquired in oil sands tests. Typical pressure versus depth plots look like the one illustrated below in Figure 7. Four pressures were reported in this particular test after five attempts. The two upper pressures were approximately 1300 kPaG. If a pressure gradient line was to be constructed, the slope would be 9.775 kPa/m. The two lower pressures were 2629 and 2803 kPaG, respectively. These are the mud hydrostatic pressures at these depths and are likely the result of supercharging. There was one measurement at the 50-metre depth, which was a casing check test. Combining this point with the other five mud hydrostatic pressures at the target formation, we have a mud hydrostatic pressure gradient of 11.08 kPa/m. This is consistent with the mud weight usually used in drilling these wells.

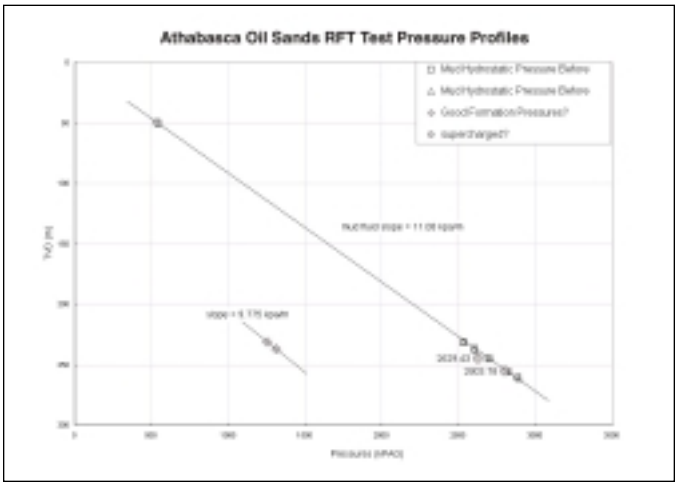

Figure 7. Typical Pressure vs. Depth Plot in Oil Sands

The two lower pressures were a result of a typical buildup (Figure 4). The real question is how valid are the two upper pressures (Figure 3).

Figure 8 shows another WFT test pressure profile. At the top right of the graph, two pressures show supercharging to different degrees. A third pressure, on the top left, was very low due to dry-test behavior. Two other pressures, on the bottom left, were also reading low as dry tests. The pressure gauge performed extremely well. The mud hydrostatic pressure gradients were interpreted from all the tests across the 14-meter interval (Figure 9).

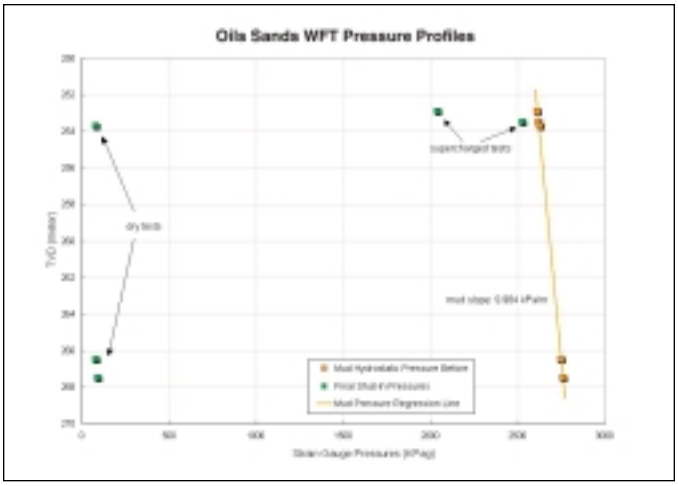

Figure 8. Typical Oil Sands WFT Pressure Profiles

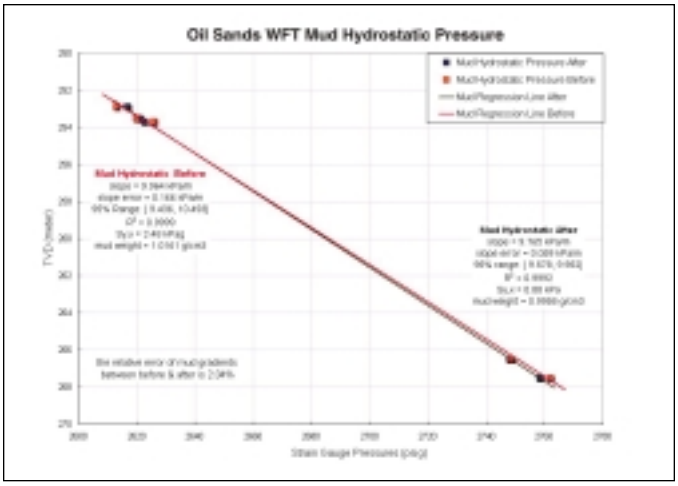

Figure 9. Mud Hydrostatic Pressure Gradients

Continued on page 13...

Testing Oil Sands... *continued from page 12*

Alternative Choices

- **Test Water Zones** – Connate water embedded in the oil sands must be in hydraulic equilibrium with hydrocarbon. Its pressure should be extremely close to that of the hydrocarbons and can be considered as the most representative. High water saturation strips within oil sands must be identified from openhole logs, in order to perform a test.
- **Use Wireline Tester Packer Systems** – Dual packer systems with MDT, FRT, or RCI, can seal larger formation test intervals. When compared with a small probe, a larger interval may improve the chances of having more mobile water included for a potential drawdown flow.
- **Increase Flow Volume** – A small volume pretest from single-probe based testers will not be good enough. Either an extended pump out flow or a large sample chamber is recommended. This ensures that a valid representative flow occurs and the anticipated formation water participates in this particular flow.
- **Order Special Tools** – Special devices may be added by modifying existing wireline testers. Adding an electronic cable to heat up the test interval before performing a test is an option. It may take a few hours to warm up a few meters of formation, particularly in a radial direction into the sands. However, this increases the chance of getting a representative formation pressure.

Testing oil sands in Alberta generally requires using the dual packer type of tools, such as Schlumberger's MDT, Precision-Drilling/Computalog's FRT, or Baker Atlas's RCI, which are more expensive than the probe-type tools. These tools stand a much better chance of getting some useful data.

Note that the reasons for using dual packers in oil sands are rather different from those of testing Lloydminster heavy oil, which undergoes cold production. Conventional DST or probe type wireline testers usually fail due to sand collapses, or micro-darcy permeability.

The Contributor

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Andy is also an international specialist on formation testing, and teaches an industry-wide technical course on wireline formation testing and interpretation coordinated by PetroSkils/OGCI (www.petroskills.com). He has over 14 years of professional experience in a variety of reservoir engineering disciplines, and has consulted internationally. He has a PhD degree at the University of Manitoba in fluid mechanics.

Canadian Well Logging History – The Start of the CWLS

As part of the CWLS's 50th anniversary the InSite has delved back into the CWLS historical archives and re-printed 2 of the first press releases from the CWLS. This also marks the kick off of a new column in the InSite – "Canadian Well Logging History". In future InSite's this column will contain articles of historical interest to the membership. If you know of an article that the membership may find of interest, please drop us an e-mail (ben@waveformenergy.com or robert_bercha@anadarko.com). In the mean time here is how it all started…

Press Release – August, 1955

An organizational meeting was held at the 400 Club Thursday evening August 4, 1955 which resulted in the formation of the Canadian Society for Well Log Interpretation. The Group will be comprised of members of the oil industry interested in Geological Formation Evaluation through the use of the many types of logs and information records taken during the course of oilwell drilling. Future plans for the group include panel discussions of technical topics of interest, delivery and discussion of technical papers, statistical studies and so on. Lectures by visiting experts in the associated sciences will be arranged. The group hopes to encourage establishment of branches in Regina and Edmonton and will start as an independent society. Elected as officers were: A. Brown of the California Standard Company, president, B. McVicar of Schlumberger Well Surveying Corporation, secretary, E.J. Burge, consultant, treasurer, A.G. T. Weaver, Shell Oil Company, at large.

Press Release – February, 1956

The name of the Canadian Society for Well Log Interpretation has been changed to "Canadian Well Logging Society". This was decided at the annual general meeting of the Society held in February, 1956 in Calgary. Also at this meeting, officers for the coming year were elected as follows: President. A.G.T. Weaver (Shell Oil company); Vice President, E. Burge (consultant); Secretary, D.W. Barrett (Lane-Wells); Treasurer, L Vladika (Hudson's Bay); Director, A.A. Brown (California-Standard).

The Canadian Well Logging Society, which meets in Calgary on the second Wednesday of every month, was formed in August 1955. Since that time active membership has grown to 40 engineers and geologists who are primarily interested in formation evaluation. The standard of papers presented at the meetings has been high and have reflected the many technical advances that have been made in evaluation methods in recent years. The many improvements in instrumentation of evaluation tools and interpretation of data have been prompted by growing realization within the oil industry that the determination of the nature of reservoir rocks and their fluid content, while far from simple, is of great economic importance. It is the purpose of this Society to encourage technical papers and discussions which will add to this particular branch of oilfield technology.

Announcement – Talk is No Longer Cheap

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

Anyone who is considering presenting at a luncheon or who has a suggestion for an interesting topic should contact Ken Faurschou at (403) 509-4073 or faurschouk@slb.com.

Drilling operations northwest of Grande Cache. Photo Courtesy Bruce Greenwood.

Century Rig 20 drilling a deep gas target in the Permian Cooper Basin, September, 2001 – Queensland, Australia. Photo Courtesy Tony Grimison.

NOTICE TO MEMBERS

In addition to VISA and cash, the CWLS now accepts Mastercard and American Express as forms of payment for luncheons, publications etc.

Laboratory Analysis Of Electrical Rock Properties And Capillary Pressure In Tight Gas Sands With Low Water Saturations

P.M. Lasswell, OMNI Laboratories Inc., K.E. Newsham, Apache Corp. and J.A. Rushing, Anadarko Petroleum Corp.

Abstract

Laboratory electrical properties and capillary pressure analysis of core samples are useful tools in understanding and calculating oil and gas reserves. Tight gas sands with low water saturations present challenges that standard laboratory methodologies can only partially address. This paper presents recent laboratory advances that have been developed to measure capillary pressure and electrical resistivities (a, m and n) under low water saturation conditions.

We first will discuss the methodologies of resistivity measurements to determine the Archie properties of m and n followed by capillary pressure tests using a 1000 psi porous plate. We will then discuss extending the electrical properties and capillary pressure tests using a vapor desorption method wherein brine salinity increases as water saturations decrease. Saturation exponent (n) variability as a function of capillary pressure dynamics is presented.

Resistivity and capillary pressure laboratory data are presented for core samples with porosities and permeabilities ranging from 4.0% to 10.8% and 0.0057 md to 0.017 md, respectively.

Introduction

Tight gas sands offer both significant gas reserves and significant challenges to the oil and gas industry. Within the laboratory, methods are continuing to be developed that help characterize and understand these systems. There are two classes of tight gas sands: those exhibiting conventional capillary pressure-based water saturation distributions; and those that exhibit sub-capillary equilibrium water saturation distributions. The latter result in ultra-low or sub-saturated wetting phase distributions as described by Newsham (1). This paper will address the measurement of electrical properties at ultra-low water saturations through the use of vapor desorption capillary pressure. The first section will provide an overview of electrical property and plate capillary pressure laboratory methods that apply to conventional reservoirs characterized by low permeability and low porosity. The second section will introduce specific vapor desorption techniques that were developed to investigate the ultra-low water saturation conditions. The third, and final section, will review two data sets that illustrate and present the results of this study.

Basic Laboratory Methods

Sample Selection.

Sample selection is a defining process for special core analysis test results. Ideally a specific uniform rock type (pore geometry) should be represented in each sample and unconformities should be avoided. Any bedding if present must be oriented along the long axis of a plug sample.

Basic physical requirements should also be met. These include: parallel and even end-faces, uniform cross sectional area and preserved rock fabric. In addition, for analysis involving the subject of this paper, electrical properties with vapor desorption capillary pressure, samples need to have dry weights of at least 50 grams and pore volumes of at least 1 cc. Smaller samples will not yield sufficient data quality.

Sample Preparation.

Most special core analysis is conducted on clean, dry and stable samples of known physical properties. The physical properties (aside from grain volumes) need to be determined at the same net confining stress as the analysis. With cleaning and drying it is particularly important not to damage or alter the rock fabric. Cool solvent cleaning is highly recommended so that any rock fabric damage is minimized. In addition, dry weights are absolutely crucial and must be well defined, stable and controlled throughout handling ... before, during and after analysis.

Electrical Properties / Plate Capillary Pressure Overview.

A basic discussion of laboratory methods used in the conventional determination of electrical properties and porous plate capillary pressure is in order prior to addressing non-conventional vapor desorption analysis. These methods include: the analysis being conducted at a net confining stress matched to reservoir conditions, a single compression cycle for the advanced testing, desaturation conducted as a drainage cycle using humidified gas to displace the brine and the use of ambient temperature.

Electrical properties as defined in the pioneering work done by Archie (2) include the formation factor (F), the cementation exponent (m) and the saturation exponent (n). Basic formulas are:

$$F = R_o / R_w \quad (1)$$

$$m = \log F / \log \phi \quad (2)$$

$$n = \log (Rt / Ro) / \log S_w \quad (3)$$

Continued on page 17…

Laboratory Analysis … *continued from page 16*

The effect of in-situ clay conductivity upon electrical properties was defined by Waxman-Smits (3) in their classic study. Here, the plotting of rock conductivity vs. brine conductivity yields an intercept, BQv that defines clay conductivity for that sample. The basic formulas are:

$$F^* = (\phi)^{-m^*} \quad 4)$$

$$F^* = Ro/Rw\ (1+RwBQv) \quad 5)$$

$$I = Rt/Ro = Sw^{-n^*}((1 + RwBQv)/(1+RwBQv/Sw)) \quad 6)$$

Porous plate capillary pressure analysis can be determined separately or in conjunction with the saturation exponent analysis. The plate provides the means whereby a sample can be uniformly desaturated along the entire sample length in a stepwise set of discrete increasing pressures up to a maximum of 1000 psi in an air / brine system. Plate capillary pressure, although time consuming, is recognized as the method best suited in modeling the dynamics of capillary pressure within a reservoir.

Centrifuge desaturation is not a recommended practice in electrical properties determinations mainly due to significant evaporation that occurs. With tight gas sands this evaporation error can exceed 20%. A secondary issue involves the potential uneven brine distribution within a sample due to residual effects of the gravitational field developed during centrifugation.

Formation Factor.

The initial step in most electrical properties testing involves the determination of the formation factor, F. This analysis is straightforward but basic protocols must be followed to avoid error and data artifacts. Each sample must be flushed with a sufficient volume of synthetic formation brine to establish rock / brine equilibrium and each sample must be 100% saturated with brine. Samples that are non-uniform and are of low porosity will exacerbate the problems associated with equilibrium and entrained gas. In particular, the samples must be flushed with brine against back pressure, soak cycles employed and resistances monitored on a daily basis with the time base set against the permeability range of each sample. For example, high permeability high porosity sandstones may well equilibrate electrically within 4 to 6 days. With a tight gas sands, stability might not actually be reached until 4 to 6 weeks have elapsed. Independent assessment for any remaining gas must also be done to assure that all gas is removed.

CoCw Clay Conductivity.

Clay conductivity determinations are useful in conventional reservoirs where the formation brine is relatively fresh (less than 50 g/L salt) and clay content is variable and generally above 5% of the grain structure by weight. CoCw analysis can also be of use where the formation brine is either variable or is not well defined.

Samples are flushed with a sequence of a minimum of three saline brines ending with the final formation brine. The rock conductivity is monitored to stability for each brine using the techniques outlined in the preceding formation factor section.

Resistivity Index and Capillary Pressure.

Typically, the saturation exponent is determined on initially clean and dry samples proceeding from 100% brine saturation to a final irreducible brine saturation, Swi. (Issues of fresh/preserved state analysis, wettability and elevated temperature are outside of the scope of this study.)

The determination of the saturation exponent n (or of incremental n values) is dependant upon two main precepts: the control of an even desaturation process through use of a porous plate and the material balance confirmed and defined value of the final brine saturation percent, Swi. During the desaturation process, the rock fabric controls the desaturation pressures needed and minimum time required. Many rock types are susceptible to desaturation that is too rapid, leading to non-uniform saturation profiles and anomalous resistivity response. Therefore, incremental pressure steps should be employed to control the desaturation process. The determination of volumetric equilibrium at each pressure step is best approached with a conservative definition of stability. In practice, three days of no volumetric change is reasonable standard of equilibrium for most rock types.

The second critical element in determining laboratory based saturation exponents, is the ability to verify Swi values. Low porosity rotary and conventional plug samples are particularly susceptible to errors in Swi due to the relatively small pore volumes involved. Specifically, production-based Swi values should be confirmed by the differences between pre and post-test dry weights and the Swi weight as well as final Dean-Stark extraction. Dean-Stark extraction must be carefully assessed with regard to the potential damage to rock structure as well as considerations to free and bound water issues. With 1 inch diameter samples uncertainties greater than 0.01 cc can introduce un-acceptable error. These errors are cumulative and are resultant from volumetric desaturation uncertainties, pore volume variability and most importantly dry weight variability.

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Laboratory Analysis … *continued from page 17*

1000 psi Plate / Membrane System.

The 1000 psi plate/membrane system was designed primarily to improve saturation exponent accuracy by lowering the final Swi saturation obtained in low porosity materials (3 to 8 % porosity). Few conventional reservoirs would require analysis with this high of a capillary pressure in order to model reservoir conditions.

Uncertainty in saturation exponent values is usually unacceptable if conventional low porosity samples are desaturated to only 70 or 80 percent using an industry standard 15 bar plate with a maximum 200 psi air/brine desaturation pressure. Note again that cumulative errors greater than 0.01 cc often produce unacceptable results.

However, where pore structures exhibit varied micro and macro pore throat components, the higher desaturation pressure allows for a more inclusive investigation of the resultant variable saturation exponent n. If the resultant n values are basically linear over the full desaturation range, the gained confidence of response is none-the-less an added benefit.

Vapor Desorption.

Capillary Pressure and vapor pressure relationships have been investigated and presented in the literature by Calhoun (4), Collins (5) and Melrose (6). More recently, Newsham (7, 8), has expanded these earlier studies to define vapor desorption as a possible mechanism to describe the capillary pressure/rock fabric/brine salinity relationships within specific basin-centered tight gas sand reservoirs. Vapor desorption methodologies were developed within the laboratory to model these systems and achieved air / brine capillary pressures in excess of 12000 psi. The basic equation is:

$$Pc = - \ln (RH / 100) RT / Vm \qquad 7)$$

The laboratory basics start with an initial desaturation of the samples to Swi using a maximum capillary pressure of 1000 psi. Both plate and centrifugation were used in the studies by Newsham (7, 8) to achieve the 1000 psi Swi step, but this investigation is limited to the use of plate capillary pressure as the appropriate methodology due to the salinity / saturation errors inherent with centrifugation.

The 1000 psi step is followed by using an electronically controlled humidity chamber to sequentially lower the vapor pressure surrounding the samples and monitoring the resultant drop in Swi at each pressure step for each sample. Typically this involves four relative humidities (RH): 90, 80, 70 and 60 percent. Weight at each step is monitored daily and on average requires approximately 20 days to reach stability for any given sample at the first 90% RH step. Subsequent RH steps required from 8 to 10 days to reach stability. Vapor desorption is used to develop high capillary pressures within each sample based on the relative humidity surrounding the samples and the brine salinity of the wetting phase within each sample. The Swi values obtained for each sample are based on these capillary forces and the pore geometry of each sample. It is a true capillary pressure relationship that is definable, specific and reversible.

Newsham (7, 8) presented vapor desorption capillary pressure as an extension of the capillary pressure curves developed using standard laboratory methods.

Case Study: Electrical Properties and Vapor Desorption Capillary Pressure

Introduction.

A total of 16 samples from 3 fields were included in an original study combining electrical properties analysis and vapor desorption analysis. Data from two representative samples will be presented in detail… providing both an outline of the methodology and a platform for a discussion of the results.

The samples were of two sizes: 1" diameter by 2" in length and 1½" in diameter by 2½" in length. The samples were initially cool solvent extracted and dried to stable weights using conditions that minimized any rock fabric alteration or damage. Physical properties were determined at the net confining stress that matched the specific reservoir conditions for each sample.

All samples were screened for physical condition and physical properties prior to inclusion in the testing program. Specifically the representative samples needed to possess excellent physical properties mentioned before: parallel end faces, uniform cross sectional area and stable rock fabric. Dry weights, pore volumes and grain volumes were repeatedly checked both before testing as well as after testing. (Note that weights were recorded to 0.001 g and volumetrics were calculated from these weights throughout the analysis program.)

Procedures: 1000 psi Conventional Electrical Properties and Capillary Pressure Analysis.

The selected samples were evacuated and pressure saturated with a 50 g/L brine solution made up of representative salts. This brine salinity was selected so that during the course of evaporation and brine concentration within the vapor desorption process, the final brine salinity would not produce a salt

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Laboratory Analysis … *continued from page 18*

saturated solution at room temperature. This selection is based both the estimation of the 50 g/L brine saturation at the 1000 psi capillary pressure point as well as the estimation of the final brine saturation at the 10000 psi capillary pressure point. Too low of an initial salinity will subject the analysis to excess clay conductivity effects and possible alteration of the clay fabric.

The samples were then mounted into electrical properties test cells with a 1000 psi plate/membrane in capillary contact with the lower face of each sample. The appropriate net confining stress was applied to each sample. This stress was maintained throughout the resistivity index / plate capillary pressure tests to the 1000 psi stability desaturation pressure point. The samples were backpressure flushed with the 50 g/L brine and 2E electrical resistances and phase angles monitored on a daily basis using a test frequency of 1 kHz. Note: Phase angles remained at or below 1 degree throughout testing. Typical electrical stability time was 2 1/2 weeks, but the key is multiple days of no resistivity change after sufficient brine volume throughput. In most cases 20 to 50 pore volumes of throughput were need before stability was reached.

The samples were then checked to be sure no gas was remaining within any of the sample pore structures before continuing to the desaturation phase.

The samples were then desaturated in place using humidified nitrogen as the displacing phase in discrete pressure steps. The initial starting pressure was 20 psi and the entire pressure sequence was: 20, 40, 60, 100, 140, 200, 400, 700 and 1000 psi. Production was monitored to insure that samples did not desaturate too quickly...usually not a problem with tight gas sands. Even so, the use of interim pressures and close monitoring of sample response is required. Stability at each pressure step was defined as no net volumetric change over three to five consecutive days. With tight gas sands, incremental daily volumetric changes can be rather small so extra care is needed to discern capillary pressure stability.

Following stability at 1000 psi air / brine, the samples were carefully removed from the test cells and immediately weighed. Extra care was taken to be sure that no sample was contaminated with the overburden fluid as all saturations are based on weight.

Procedures: Electrical Properties and Vapor Desorption Capillary Pressure.

Samples were next placed in an electronically controlled humidity chamber at 90 percent relative humidity / 30 degrees C. (90 percent relative humidity roughly translates to 2000 psi.) Sample weights were monitored daily. As each sample equilibrates to the relative humidity of the chamber, the brine lining the pores loses water through evaporation and the brine concentrates as a result of the evaporation. The evaporation will continue for each sample until capillary pressure equilibrium is reached within the pores of each sample. As mentioned before, this is truly a capillary pressure based system within which each sample establishes a given brine saturation at a given capillary pressure based on the pore geometries of that sample.

Weights were recorded to 0.001 g and stability was defined as a minimum of three consecutive days with weights bracketing a given number plus or minus 0.005 grams on average without any remaining upward or downward trends. As weights tend to change slowly, weights can change less than 0.005 grams from one day to the next, yet after 7 days, the weights might still be dropping. Therefore, it is the weight trend that must stabilize. Figure 1 summarizes gravimetric saturation changes on 2 generic (but actual) samples during vapor desorption capillary pressure tests.

At stability, the samples were weighed and immediately loaded into 2E electrical test cells and net confining stress was applied. Resistances were then monitored on a daily basis until stable for each sample. On average, electrical stability was reached within 3 to 6 days. Each sample was removed from the test cell and weighed immediately.

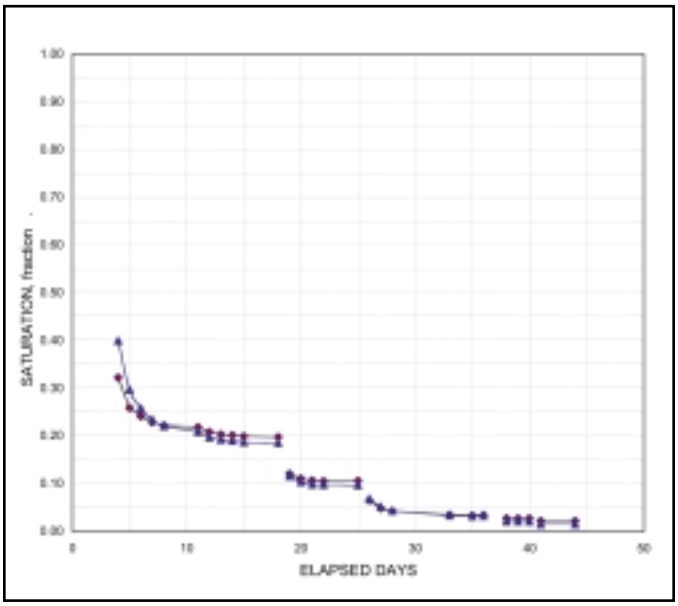

Figure 1. Vapor desorption capillary pressure stability plot: fractional saturation vs. elapsed time.

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Laboratory Analysis … *continued from page 19*

Samples were placed back into the electronically controlled humidity chamber at 80 percent relative humidity / 30 degrees C and the process was then repeated as for the 90 percent RH step. This was again repeated at a 70 percent RH step and finally a 60 percent RH step. The criterion for stability remained the same for each stage of the process.

Upon final resistivity stability at the final RH step, the samples were removed from the test cells and reweighed. The samples were then Dean-Stark extracted with toluene for final water saturation verification. Note: Samples with clay or other structures that might be damaged by this extraction process should not be subjected to this extraction step and proceed directly to final drying using the pre-test drying methodology. Salts then will need to be backed out of the final weights through either cool solvent extraction or by calculation.

The samples were redried following extraction using the original methodology and stability criterion of pre-test drying. This step is extremely important, as the post-test dry weights are often the most accurate benchmark for calculating the brine saturations for a given sample.

CoCw.

Depending upon the clay content and structure of the samples being analyzed, CoCw analysis could be an important test to include in the analysis program. The electrical properties investigations to 1000 psi are conducted with a brine concentration of 50 g/L. As vapor desorption proceeds, the brine is concentrated to nearly 250 g/L and should there be significant clays present, electrical response will reflect the contribution of the clay conductivities, especially with respect to the changing brine salinities.

Calculations: Conventional 1000 psi Electrical Properties / Plate Capillary Pressure.

Formation factor calculations were based on the pre-test physical properties and the initial brine resistivity at 50 g/L. Resistivity index resistivity calculations are also based on the initial formation factor with the 50 g/L brine salinity. Resistivity index and plate capillary pressure saturation calculations were tied to the final saturation at the 1000 psi capillary pressure point. This Swi calculation is not necessarily a straightforward and easy process, especially with tight gas sands.

Experience has shown that the weight differences most accurately define final brine saturations: Swi weight minus the dry weight. In addition, as dry weights often change between the pre-test and post-test steps, the question is posed as to which dry weight should be used in the calculations. Again, experience has shown that in most cases the post-test dry weights provide the most accurate calculation of Swi following the 1000 psi step. This is decidedly not the case with some clay sensitive materials following Dean-Stark toluene extraction and therefore each set of rock lithologies must be considered separately. Should significant weight changes occur between pre and post test steps, consideration should be given to the measurement of post-test properties...especially the pore and grain volumes.

Calculations: Electrical Properties / Vapor Desorption Capillary Pressure.

Resistivity, brine saturation and salinity calculations are treated the same for each sample at each vapor desorption / resistivity index point.

Resistivity calculations at each vapor desorption step were based on two readings for each sample: the resistance after 24 hours and the final resistance at stability. Although resistance changes were relatively small for each sample at each step, both readings were included in the calculations of an average n value for each sample. It was assumed that much of the resistance change is due to continued evaporation from handling therefore each reading should be considered valid. At the very least a resistance range is given at each vapor desorption point.

Within each sample, as the brine concentrates through the process of vapor desorption, Rw, no longer is a constant. Therefore the next calculation at each vapor desorption pressure / resistivity index step is to calculate the associated Rw based on the weight before and the weight after the resistivity measurements. At the 1000 psi point for each sample, a given Swi is calculated and the salinity is assumed to be 50 g/L. All desaturation up to and including the 1000 psi point were conducted using humidified gas to minimize salinity change. Therefore for each sample there is a given weight of salt within the volume of brine. As the brine within each sample loses volume a new Rw can be calculated based on the g salt/unit of new brine volume. If clay conductivity is deemed to be insignificant then a new Ro for each sample, before and after each vapor desorption / resistivity index point, is calculated from a rearrangement of Archie's formation factor equation:

$$Ro = F * Rw \qquad 8)$$

If clay conductivity is significant then the formation factor at each vapor desorption step is not a constant and therefore must be calculated using Waxman-Smits based CoCw methodology.

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Laboratory Analysis … *continued from page 20*

Here, by substituting in the new Rw with a known BQv, a corresponding formation factor can be calculated. From the calculated formation factor, a corresponding Ro is calculated using before and after weights at each vapor desorption / resistivity index point using the above formula. Based on the new Ro, the resistivity index point is calculated using Archie's resistivity index, equation:

$$I = (Rt / Ro) \qquad 9)$$

Saturations at each vapor desorption / resistivity index point for each sample are calculated using the before and after weights at each point and the final dry weight. Sample handling therefore becomes very important as to not introduce error by de-coupling the resistances from the saturations since both are dependent upon "known" salinities. In part this is normalized by using pre-point weights with the 24 hour resistance reading and post-point weights with the final resistance reading at a given point.

Weight differences, although rather small at higher vapor desorption pressures, produce correspondingly large changes in Rw and brine saturation calculations. Therefore, all handling and weight stability steps must be taken with great care. In addition, should contamination occur at any step, then the test must be halted, the sample recleaned and the test restarted.

Data Sets.

Two data sets are presented to illustrate the vapor desorption / electrical resistivity analysis hi-lighted by ultra-low water saturations.

The first sample, 16, has a porosity of 4.0 % and an air permeability of 0.0057 md. The equivalent CEC is relatively low at 0.0063 meq/g. In Figure 2, the combined plate and vapor desorption based capillary pressure curve and resistivity index response seem to be rather typical for this rock type.

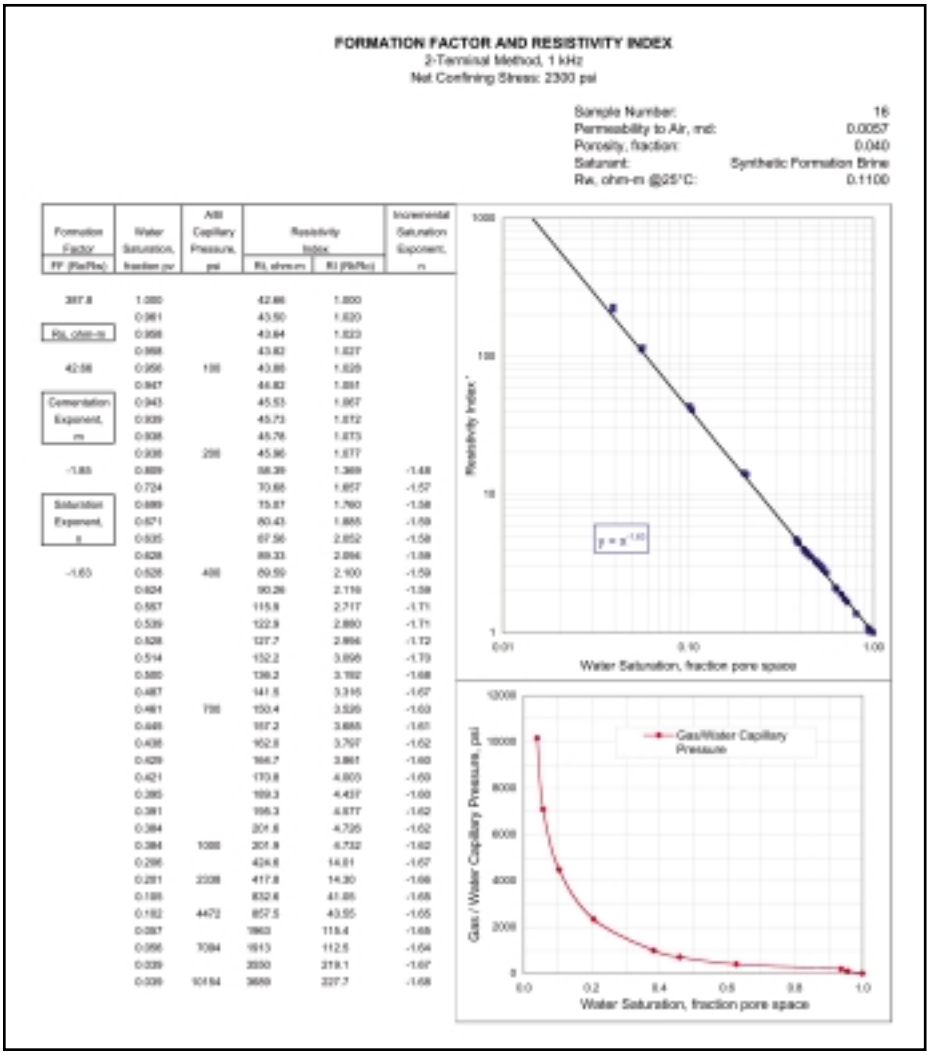

Figure 2. Resistivity Index and Capillary Pressure Data Sample 16.

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Laboratory Analysis … *continued from page 21*

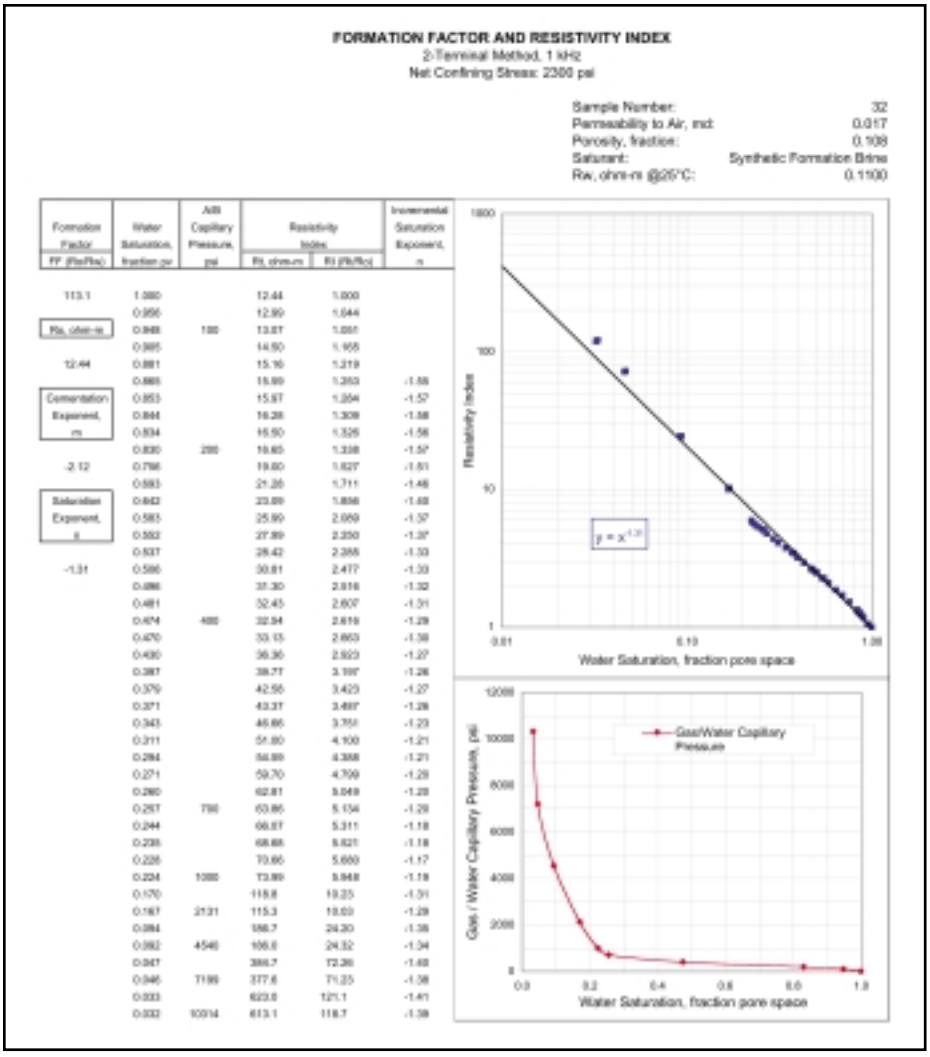

Figure 3. Resistivity Index and Capillary Pressure Data Sample 32.

In Figure 3, sample 32, has a porosity of 10.8 % and an air permeability 0f 0.017 md. The equivalent CEC is 0.0454 meq/g, which is moderate to moderately high. Somewhat atypically, this sample exhibited less of a transition in the capillary pressure data.

For both samples, several points of common process are:

1. Individual incremental saturation exponent values were calculated to show the variation (or lack of variation) in "n" over the entire testing range.
2. Rt and Ro values were normalized to 77 degrees F.
3. Capillary pressure curves are shown as a continuum between the 1000 psi porous plate and vapor desorption data sets.
4. Vapor desorption capillary pressures are calculated from the relative humidity, temperature and saturating brine salinity. These are specific for each sample and should be noted in the data sets.
5. The resistivity index data are also reported as a continuum for each sample. Linearity is exhibited over a significant extended range of brine saturations.
6. Stability time for the vapor desorption capillary pressure steps ranged from the maximum at the initial RH point (20-25 days) to a minimum at the final two RH points (5-7 days).
7. Resistivity stability for the vapor desorption steps ranged from 3 to 6 days.

Continued on page 23…

Laboratory Analysis … *continued from page 22*

8. Linearity of the resistivity index response within the vapor desorption test range suggests that the wetting phase (brine) remains continuous and intact over the rock surfaces.

In general, the 16 samples studied exhibited similar results as the two data sets summarized in this paper. Data continuity was exhibited both in the electrical response as well as the capillary pressure response. All samples showed very low final water saturations that were controlled by the capillary forces within each sample. In addition, these low brine saturations tended to model the reservoir brine saturations.

It should be noted that the vapor desorption process was shown to be reversible within samples studied to-date. Moving a sample back to a higher relative humidity setting results in a re-absorption of water into the wetting phase brine...back to the original weight/saturation observed at that setting.

Clay Effects and Salinity Normalization.

Clay conductivity combined with changes in brine salinity will alter sample resistivity response. In an effort to illustrate these effects, three sets of data are graphically presented in Figures 4 and 5.

The first set of data represents the original measured data and is presented in both Figures 4 and 5 as the red symbols. These data represent the lowest resistivity index values shown.

The second data set shows the results of the salinity normalization involving a re-calculation of the resistivity response for the 50 g/L salinity data and the vapor desorption data as if the brine salinity was 250 g/L.... similar to the final brine salinity at the end of the vapor desorption testing. In essence the data is presented as if the whole of testing was conducted with a brine salinity of 250 g/L. These calculations are done using the Waxman-Smits resistivity equation, the BQv intercept (or the estimated equivalent from CEC), and the ratio of the two Rw values (the actual g/L and 250 g/L). Initially, the effects of clay are backed out of the resistivity index data using Waxman-Smits resistivity equation 6:

$$I = Rt/Ro = Sw^{-n^*}((1 + RwBQv)/(1+RwBQv/Sw)).$$

Then, the clay conductivity contribution is recalculated based on the new higher brine salinity (250 g/L), yielding a new resistivity response. These data sets are shown in figures 4 and 5 as the intermediate (light blue symbols) resistivity index points. In particular, this method calculates higher incremental resistivity index data, n, over the initial 1000 psi capillary pressure portion of the data sets. Negligible resistivity change occurs for the resistivity index data within the vapor desorption data range as little salinity adjustment was involved. This data set presents a reasonable resistivity normalization where clay conductivities are present and the formation brine salinity is high. Normalizations to other salinities can be performed as required.

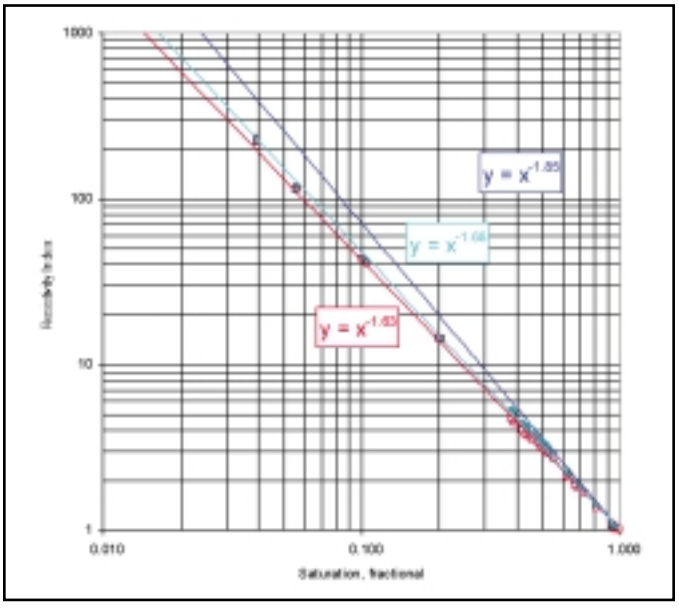

Figure 4. Sample 16 Resistivity Index Response vs. Clay

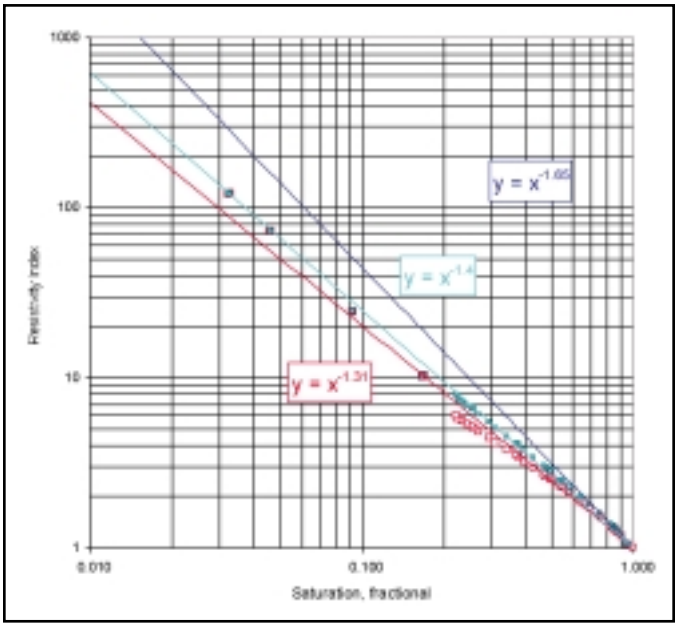

Figure 5. Sample 32 Resistivity Index Response vs. Clay

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Laboratory Analysis … *continued from page 23*

The third data set is simply the Waxman-Smits shaly saturation exponents: resistivity index data calculated as if no clay conductivity existed. These data are shown in Figures 4 and 5 (dark blue symbols) as the highest resistivity index values.

Conclusions

Vapor desorption has been shown to be a method that both models capillary pressure (Newsham 7, 8) and extends electrical response into the lowest of saturation ranges observed in tight gas sands with ultra-low water saturation.

The linearity and continuity of the resistivity index data reinforces the linkage observed between vapor desorption data and traditional capillary pressure data. The electrical response indicates that the vapor desorption desaturation process is uniform, continuous and rock dependant without hysteresis effects.

Recalculation of the 1000 psi and vapor desorption resistivity index response based on a selected brine salinity (eg 250 g/L) provides a normalization of parallel clay conductivity effects.

The vapor desorption and "best practice" electrical properties methodologies could be employed to extend electrical resistivity response investigations into those materials characterized by moderate as well as lower rock qualities.

Nomenclature

F = formation factor

Ro = resistivity of 100% saturated rock, ohm m

Rw = resistivity of test brine, ohm m

m = cementation exponent

ϕ = porosity, fractional

n = saturation exponent

Rt = resistivity of partially saturated rock, ohm m

Sw = brine saturation, fractional

F* = shaly formation factor

m* = shaly cementation exponent

B = equivalent conductance of clay exchange cations, liter equiv^{-1} ohm^{-1} m^{-1}

Qv = effective concentration of clay exchange cations, meq ml^{-1} at Sw = 1

I = resistivity index

n* = shaly saturation exponent

Pc = capillary pressure, psig

Co = conductivity of 100 % saturated rock, mho cm^{-1}

Cw = conductivity of test brine, mho cm^{-1}

RH = relative humidity, percent

R = universal gas constant, 8.314 J/Mol K

T = absolute temperature, degrees Kelvin

Vm = molar volume of water

CEC = cation exchange capacity, meq/g

Acknowledgments

We would like to express our thanks to the management of OMNI Laboratories Inc., Apache Corporation and Anadarko Petroleum Corporation for their continued support and permission to publish the results of our study.

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About the Authors

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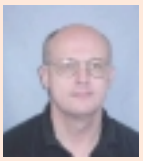

Jay A. Rushing is a Senior Reservoir Engineering Advisor for Anadarko Petroleum Corp. in Houston, Texas, USA. He is currently a technical advisor for many exploration, development and production activities for Anadarko's unconventional natural gas assets in East Texas, North Louisiana, Mississippi, and Alabama. Dr. Rushing has more than 15 years of reservoir engineering experience in all unconventional natural gas resources, including tight gas sands, basin-centered gas systems, coalbed methane, and naturally fractured gas shales. He has also authored more than 30 technical papers – many dealing with tight gas sand characterization. His professional interests include unconventional natural gas reservoir and production engineering; integrated reservoir description and characterization studies; well and reservoir evaluation using production performance analysis and pressure transient testing; core-based petrophysics; and applied reservoir simulation. Dr. Rushing was graduated from Texas A&M University with B.S. degrees in civil and petroleum engineering (with honors); an M.S. degree in petroleum engineering; and a Ph.D. in environmental and petroleum engineering.

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INCORPORATED – January 21, 1957

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

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

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Tech Corner: NMR Logging Basics

Paul Pavlakos and Don Tiller, Precision Energy Services

Introduction

For over a decade, NMR (Nuclear Magnetic Resonance) logging has added information that is not normally available from a standard logging suite of tools. Because the NMR tool is not typically run, particularly in developed fields, not everyone is familiar with this tool. The intention of this write up is to assist those that have not worked with the tool to become more comfortable with how the NMR tool works, and what it can do for you.

Some of the applications of the NMR tool are:

- matrix independent porosity measurement
- distinguish between bound and moveable water
- analyze pore sizes
- permeability calculation
- fluid and hydrocarbon typing

Basic Tool Physics

The physics behind the NMR tool are complex and only an overview will be presented here. Basically, a NMR logging tool consists of a permanent magnet supplying a strong magnetic field and an antenna that is used to stimulate the formation fluid and to receive the resultant electromagnetic pulses emitted from the fluid. Free protons (hydrogen nuclei) in the formation have magnetic moments that are ordinarily randomly oriented. However, in the presence of the strong magnetic field of the NMR tool the proton magnetic moments will orient such that there is a net magnetization parallel to the tool's magnetic field. The time it takes for this magnetization to reach its maximum value in the direction of the strong field is characterized by T1, the longitudinal buildup time (Figure 1).

A series of radio frequency (RF) pulses (called CPMG sequence after Carr, Purcell, Meiboom, and Gill) are used to perturb the net magnetization. First, a 90° pulse is used to orient the net magnetization transverse to the strong field. This transverse magnetization precesses about the strong field and emits radio frequency energy, which is measured with the tool's antenna. Because of proton interactions, the transverse magnetization quickly decreases with time, thus the antenna signal decreases with time. A subsequent 180° RF pulse is used to stimulate an increase in the transverse magnetization which again quickly decreases – this is a stimulated echo. A series of 180° pulses spaced by a certain echo time, TE, is used to stimulate an echo train with each subsequent echo lower in amplitude than its predecessor. The rate of decay in echo amplitude is the T2, the transverse decay time (see Figures 1, 2).

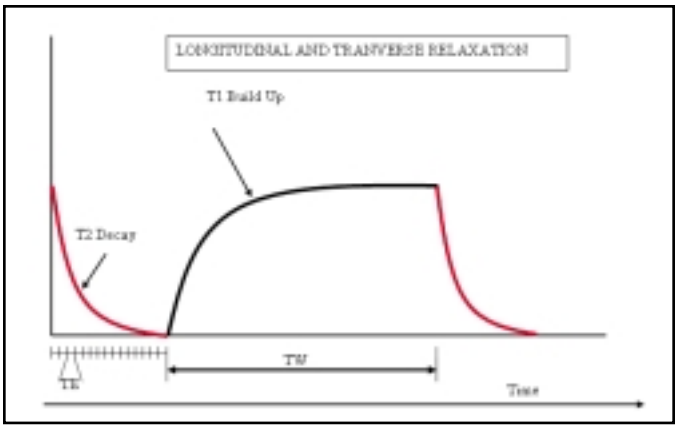

Figure 1 – T1 longitudinal build up and T2 transverse relaxation times

Between echo trains, the formation fluid is allowed to relax for a certain wait time, TW, prior to the next 90° pulse. The strength of the initial magnetization is dependent upon the wait time and the longitudinal relaxation time of the fluid in the formation. The various parameters of the NMR experiment: the echo spacing (TE), the wait time between echo trains (TW), and the number of echoes stimulated (TN), can be varied to optimize the measurement for a particular environment, within the constraints of the logging tool.

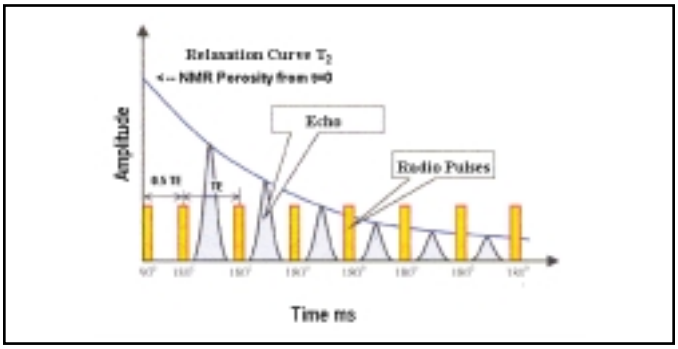

Figure 2 – CPMG spin-echo train is used to generate NMR T2 decay signal. The spin-echo series begins with an initial 90° pulse, followed by series of 180° pulses. After each pulse, there is a decrease in echo amplitude. The total porosity from NMR is calibrated such that it will be measured at time t=0.

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The logging parameters may be adjusted for specific types of formations and fluids. In general, the wait time will be in the range of 1 to 8 seconds; the number of echoes will be in the range of 100 to 1000; and echo spacings will be in the range of 0.4 – 4.8 msec. The wait times for water, oil and gas will vary considerably depending on the characteristics of the reservoir.

Porosity from NMR

The NMR tool responds to liquid filled porosity and is calibrated so that the initial amplitude of the signal is proportional to the formation porosity (Figure 2). A typical calibration is in a 100% porosity water tank. Porosity from NMR tool is generally matrix independent; however, depending upon the activation parameters, the tool may not detect liquids with short T2 (such as clay-bound fluid or heavy oil) or with long T1 (such as fluid in a vugular pore structure). In order to measure a total porosity, TW must be long enough to ensure full polarization and TE must be short enough to measure the fast decay components. If TW or TE is too short, the measured porosity will be less than the total porosity. Also, as the NMR tool responds to free hydrogen, the measured porosity will be less than the true porosity where the pore space contains fluid with a hydrogen index less than one (such as gas).

Zone of Investigation

There are 2 types of NMR tools available: one type is run centralized and the other is run decentralized. For a centralized NMR tool, the zone of investigation or sensitive volume is a thin cylindrical volume (Figure 3). The zone of investigation for an eccentered tool is some distance into the formation from where the tool is in contact with the borehole wall. The depth of investigation will vary from tool to tool and on the frequency of the RF antenna. By sequentially changing the frequency of the antenna, the formation can be evaluated layer by layer successively. There are wide variations of tools in the industry, many of them offering multiple frequencies.

Figure 3 – For a centralized type NMR tool, the zone of investigation is typically a thin cylindrical layer (0.5-0.8 mm) and about 350 mm diameter. This diameter will vary from tool to tool. The diameter of investigation can be sequentially measured by changing the frequency.

T2 Inversion

It is often more convenient to work with data in the T2 domain than in the time domain. The inversion of the data (the transformation from time domain to T2 domain) is a mathematical process explained as follows: the measured signal, as a function of time, can be described as a weighted integration of many different exponential decays as shown the top left of figure 4. The weighting function is the T2 spectrum and can be determined by recasting the integral and numerically solving the resultant integral equation, as shown in the bottom right of figure 4. The calibrated spectrum displays porosity as a function of T2. The

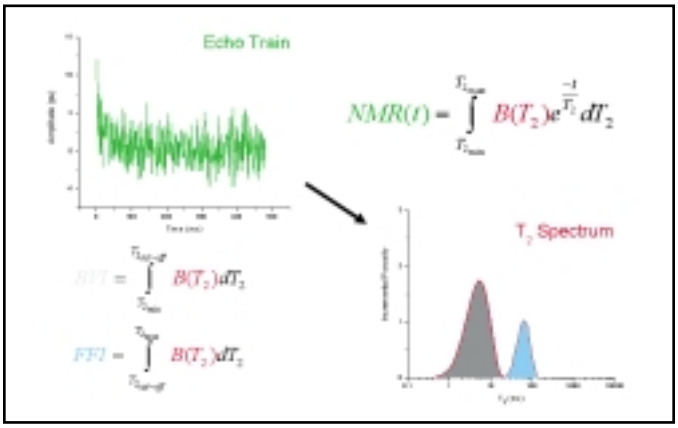

Figure 4 – Inversion process of raw echo data from standard time domain into T2 domain. This involves solving an integral equation in terms of T2. The result is a T2 spectrum in lower right hand corner. In this example, a bimodal distribution is seen, which leads to a cut-off between BVI (Bound Volume Index) and FFI (Free Fluid Index).

area under this spectrum is the total porosity. Analysis of T2 spectrum can yield information on the porosity components of the reservoir-the free fluid and bound fluid.

Pore Distribution Effects

Figure 5 shows the effects that formation pore size has on the T2 decay rate. This is shown in the standard time domain. Smaller pore sizes will tend to have a fast decay rate, where as larger pore sizes will tend to decay slower. These times can be separated out and displayed in a bin distribution on the log which will indicate relative pore space size.

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Porosity Model

A typical porosity model is shown in Figure 6. In this diagram, MPHS is the total porosity and MPHI is the effective porosity. MCBW is the clay bound water. MBVI (also referred as BVI) is the capillary or matrix bound water. MFFI (also referred as FFI) is the moveable fluids or free fluid index. If a standard open-hole analysis is available, a comparison of MBVI to open-hole BVW can be an indication of how much water will be produced. Also by comparing porosities from neutron, density, and NMR, one can determine hydrocarbon typing so that the MFFI can be resolved into moveable water, oil and gas.

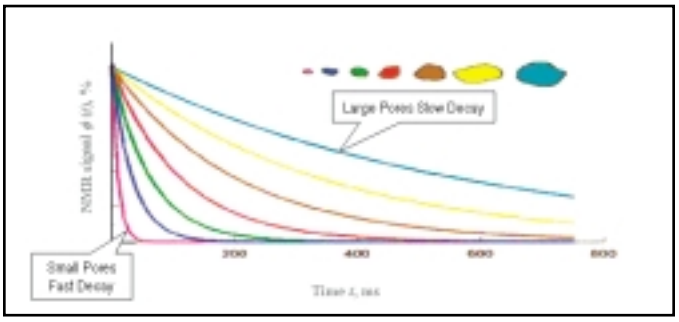

Figure 5 – Effects of pore size distribution on T2 decay rate. The smaller the pore size, the faster the decay rate.

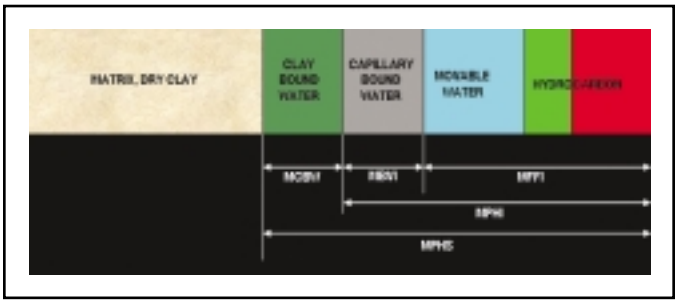

Figure 6 – Typical porosity model used in NMR interpretation is the volumetric sum of all the components.

T2 Cutoffs for Sand

Figure 7 illustrates standard T2 cutoffs in sandstones for the clay bound water (4 ms) and for capillary bound water (33 ms). These numbers may vary for different formations and areas.

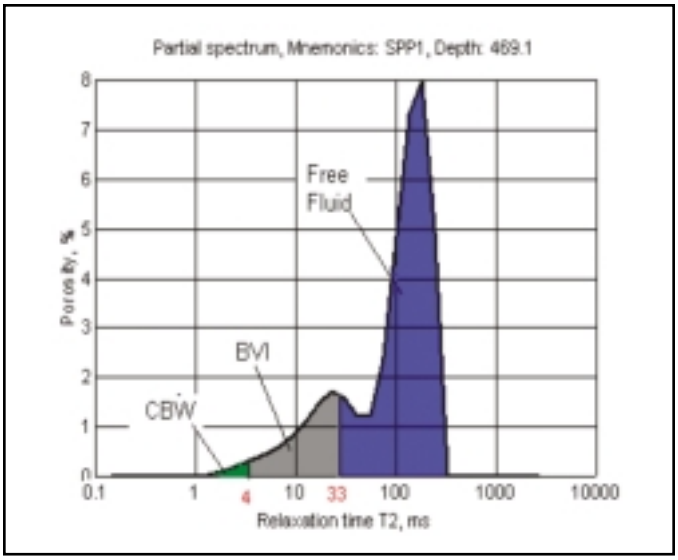

Figure 7 – Typical T2 cutoffs in sandstones for clay bound water (CBW=4 ms) and for capillary bound water (BVI=33 ms).

Permeability from NMR

There are several models available to compute permeability from the NMR tool response. All models are empirical and need to be calibrated to core data to produce acceptable permeability numbers. Probably the most common model is that from Timur-Coates. A simple form of this equation is:

$$K = \left(\frac{\Phi}{a}\right)^{b} \left(\frac{FFI}{BVI}\right)^{c}$$

The porosity in this case, FFI and BVI must be in percent. The permeability output, K, is in md. The porosity input can be either the total porosity or the effective porosity. If the NMR porosity is too low (such as in a gas or heavy oil reservoir) porosity from an external source should be used (such as from a density measurement). The constants a, b, and c can be optimized for a particular reservoir based upon core perm data (typically, a ~10, b ~4, and c ~2).

Range of T2

Figure 8 shows the various ranges for different fluids and environments. Note that heavy oil will fall in the lower T2 range near the clay bound water. Light oils will fall in the higher T2 numbers.

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Determination … *continued from page 30*

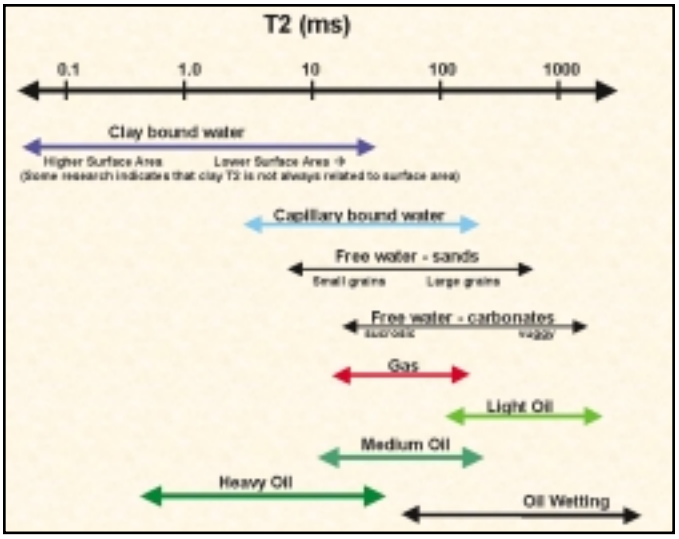

Figure 8 – Range of T2 for various fluids. Courtesy of NMR Petrophysics, Inc. 2002

Spectral Difference – Dual TW

The spectral difference method is used to identify hydrocarbons. Dual wait times (TW) are typically run and subtracted from each other in order to eliminate the water signal so that only hydrocarbons are left in the spectrum. Typically, water has a lower recovery time than light oil and gas and the wait times are chosen so that water will fully recover in both experiments and gas or light oil will not fully recover in shorter wait time. Analyzing the difference between the spectra can yield information on the content of gas or light oil.

Shifted Spectrum – Dual TE

The shifted spectrum technique is similar to the spectral difference method, except now the echo spacing times (TE) are varied instead of the wait times. The decay rate is dependent upon diffusivity of the fluid – typically, gas has a higher diffusivity than liquids. Analyzing the difference between the two spectra can yield information on the content of gas. There will be a significant shift in the T2 spectrum when gas is present and no significant shift where only liquids are present.

Log Quality Control

Logging speeds will vary depending on the tool, type of experiment, and number of frequencies involved. Typical logging speed is very slow; in the order of 0.5-4.0 m/min. Shop calibration is usually done monthly and is performed in a large tank of water. There is a before survey calibration check performed on location to verify the electronics. NMR porosity repeatability should be +/- 1 pu. BVI repeatability should be +/- 1.5 pu and FFI should be +/- 0.5 pu. In clean sands, NMR porosity should match the density porosity if the formation is water or light oil bearing. If gas or heavy oil is present, the NMR porosity will read low compared to the density, if not corrected.

Example Gas and Light Oil

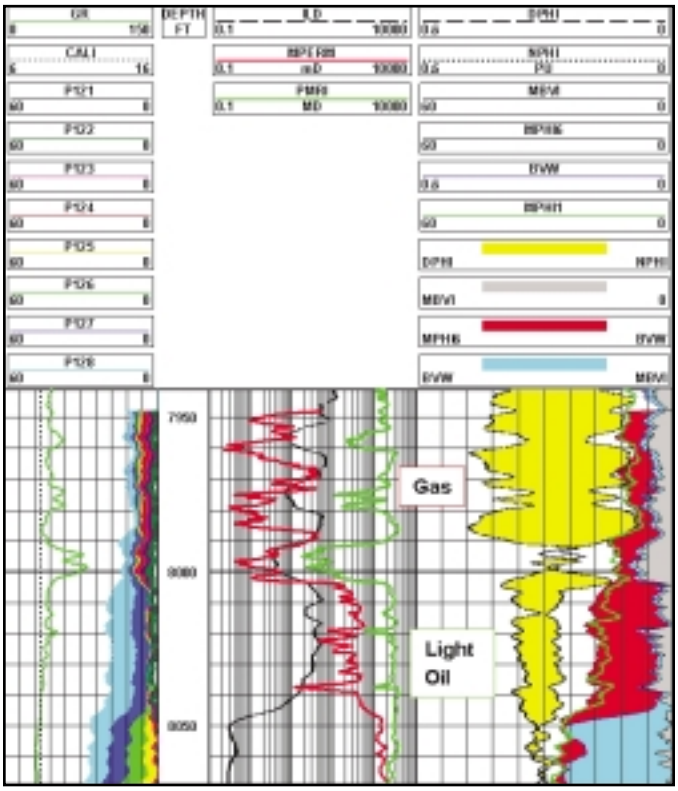

Figure 9 – This NMR log was run with dual wait times of 1 sec (MPHI1) and 6 sec (MPHI6). There is not much porosity gained with the longer wait time across the gas or the light oil intervals. Because there is a difference in NMR porosity and density/neutron from 8010-50, there must be a significant decrease in hydrogen index. Therefore, this must be due to either very light oil, or some mixture of gas/condensate. Courtesy of NMR Petrophysics, Inc. 2002

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Example Water and Light/Heavy Oil – NMR Data Only

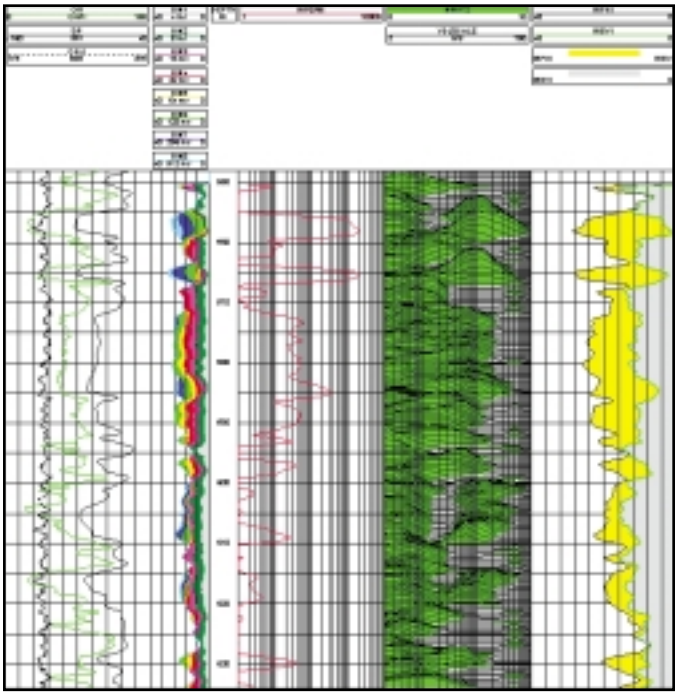

Figure 10 – NMR log in shaly sand with heavy oil present. Bin data is presented in Track 2 with finer grains in the short times and coarser grains in the longer times. Because heavy oil has a very low T2, it generally dominates the bound fluid signal. Sometimes the heavy oil T2 signal is so low that it is totally missed. This results in the MBVI to read too high and the total porosity, MPHI, to be under called. Courtesy of NMR Petrophysics, Inc. 2002

Example Water and Light/Heavy Oil – NMR Data with Conventional

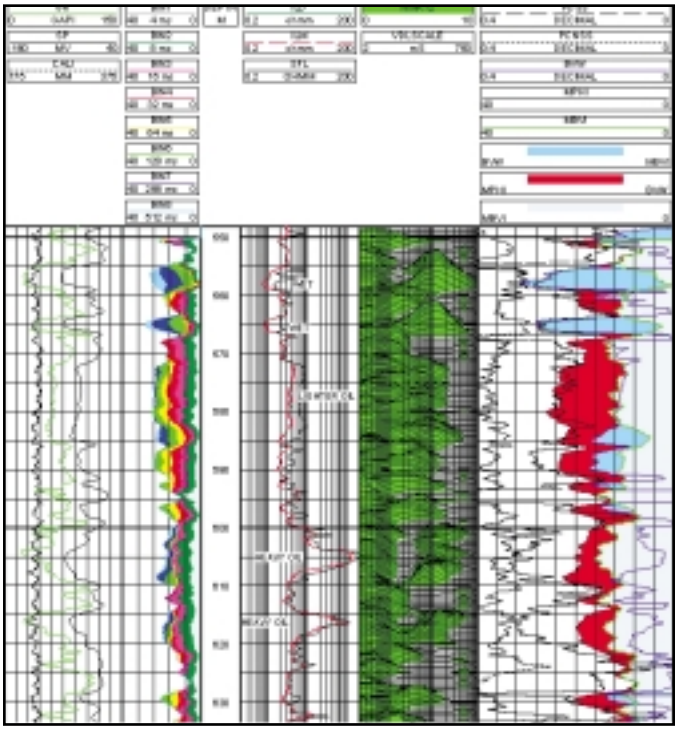

Figure 11 – Same example as previous but with conventional OH data displayed. Across the wet zones and the lighter oil, there is good agreement between the conventional OH data and the NMR data. The NMR porosity and the density porosity are very similar. Also note that MBVI from NMR is reading about the same as BVW computed from conventional OH across the lighter oil interval. Heavy oil can be identified from the higher resistivity and from the NMR porosity, reading lower than density porosity. The MBVI from NMR is higher than BVW across the heavy oil because of its low T2. Courtesy of NMR Petrophysics, Inc. 2002

Reference

Stambaugh, B.: NMR Logging Technology Course, NMR Petrophysics Inc., Houston, 2002

Biography

Paul Pavlakos graduated from the University of Calgary in 1981 with B.Sc. in engineering and has been employed in the petroleum wireline industry since then. He is currently employed as a Senior Formation Evaluation Engineer in Precision Energy Services in Calgary Geosciences Centre. He started his career as a field engineer and worked international from 1986 to 1994. In 1994, Paul transferred to the Houston Computing Centre with Computalog and subsequently transferred to Calgary in 2000.

Don Tiller is currently a Research Scientist with Precision Energy Services in Fort Worth, Texas. He began his career with Computalog as a wireline field engineer after obtaining a M.Sc. in nuclear physics from the University of Saskatchewan. Don transferred to Research and Development after working as a field engineer for 5 years in western Canada.

UPCOMING EVENTS

June 8th, 2005
CWLS TECHNICAL LUNCHEON PRESENTATION
Fairmont Palliser Hotel, Calgary, AB
Speaker and Topic TBA

June 19 – 22, 2005
AAPG 2005 ANNUAL CONVENTION
Calgary, AB
Exploring Energy Systems
www.aapg.org/calgary/

June 26 – June 29th, 2005
46TH ANNUAL SPWLA SYMPOSIUM
New Orleans, LA, USA

August 8 – 11, 2005
EARTH SYSTEM PROCESSES 2
Calgary, AB
www.geosociety.org/meetings/esp2

September 7, 2005
CWLS 50TH ANNIVERSARY LUNCHEON
Fairmont Palliser Hotel, Calgary, AB

October 5 – 6, 2005
JAPAN FORMATION EVALUATION SOCIETY
11th Formation Evaluation Symposium
Chiba, Japan

December, 2005
PARIS 2005 FRACTURED RESERVOIRS
http://www.la-said.org/diagraphies/

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

Ben Urlwin (ben@waveformenergy.com) at (403) 538-2185.

Robert Bercha (robert_bercha@anadarko.com) at (403) 231-0249

Discounts on business card advertisement for members.

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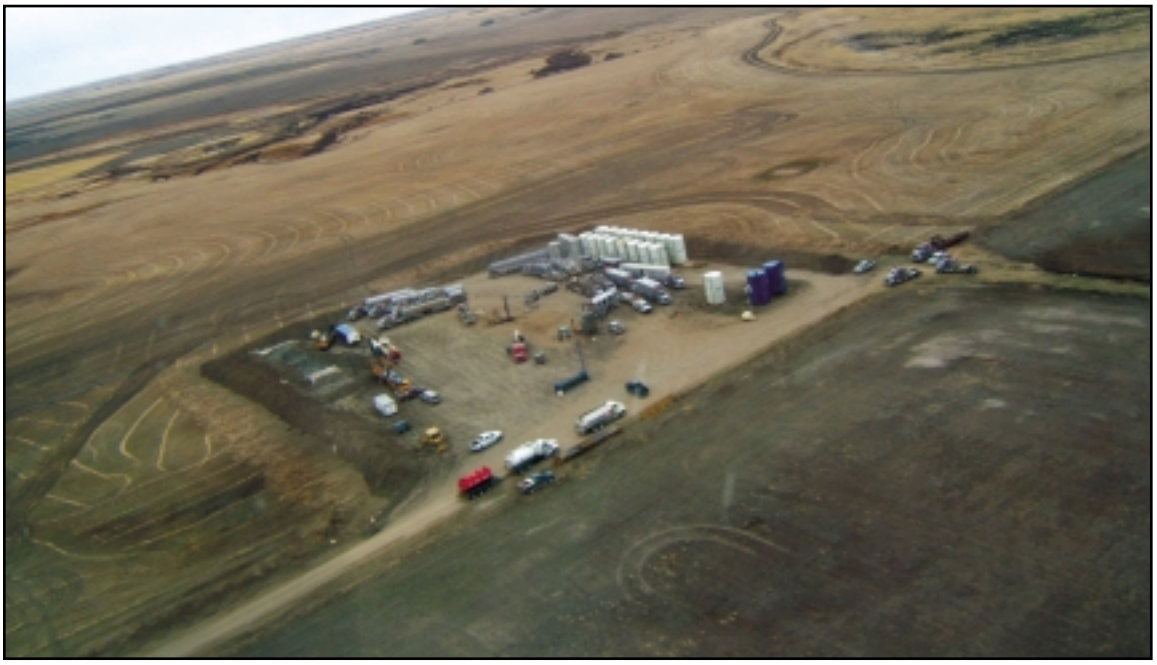
A.T. (Bill) Weaver recently passed on in Victoria attended by his wife, Joy, and two daughters.

Bill gained his degree in Petroleum Engineering after the war in Britain and came to work in Canada with Shell, and with whom he served in various parts of the world.

As one of the founding members of the CWLS he was active in the Society till his retirement from Shell to Victoria, where he became Chief Petroleum Engineer for the BC Energy and Mines until his final retirement in '85. Bill, during his tenures in Calgary greatly supported the CWLS with his characteristic determination and vigor, and was awarded an Honorary membership for his services.

A mudfish in the sump – providing the ground for the SP tool. Photo Courtesy Robert Bercha.

Logging operations in the Sinclair Area, AB. Photo Courtesy Robert Bercha.



Frac operations for a Bakken horizontal well in SE Saskatchewan. In the photo can be seen the 4 pumpers, 3 nitrogen trucks, command shacks and the eighteen 400 barrel tanks required to complete the operation. A total of 240 tonnes of sand was pumped in this multi-stage frac completion. Photo Courtesy Ben Urlwin.

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