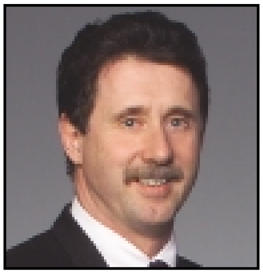
InSite

CWLS Newsletter
MARCH 2005

Table of Contents

Cover Photos: *Production testing of a gaswell in the Harlech Area, AB. Photo Courtesy Scott Hadley*

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.



President's Message

Firstly, I'd like to congratulate the outgoing President, Jeff Levack for an outstanding job. It has been great working with Jeff over the past 12 months, I've learned much.

I'm proud to be the President of the oldest professional logging society in the world as it moves into its 50th year! I'd like to see the society continue to flourish under my guidance this year. In order to attract new members and offer existing members value, we need to provide good reasons for joining our Society. There are several areas that I'd like to continue to see excellence and others where I think we could add even more value to the membership.

Monthly Luncheons.

First and foremost, we are a technical society and our technology transfer vehicle is the monthly luncheon. In my previous role as V-P and before, I have organized around 15 CWLS lunch talks, including the past 3 President's award speakers. It is essential that we maintain the quality of our lunch speakers. It has become clear to me that there are topics of primary interest to the membership and then 'other topics'. If we can attract quality 'non-commercial' speakers, addressing these primary topics, we will continue to see growth. On several occasions last year, our attendance was more than 175 people, outstanding!

I'd like to continue to promote the Vice-President's award for the **best local** oil company or academic speaker. I'd like to increase the amount of both the President's award (currently $1000) and the Vice President's award (currently $500) to encourage more local speakers. I'll be approaching the executive on this at our next committee meeting.

Subsidized Training.

The success of the Production logging school last fall was probably due to 2 factors – an excellent lecturer, Bob Maute, and the "right price". The event sold out quickly, with more than 50 people attending – many, new members, who joined to take advantage of the excellent course rate. Sadly, as much as I tried, we still only just lost money on this course! So, this year I'd like to see 2 such subsidized schools, with an even heavier CWLS subsidy applied! There is considerable interest in NMR training amongst the membership, so this is likely to be one of the schools!

Collaboration with other Societies.

The joint conference with the SPWLA promises to be a resounding success. We have more than 100 people registered, a tremendous slate of speakers from all over Canada and North America, plus Kananaskis!...what more could we ask? I'm pleased to have suggested this conference to the SPWLA, it's something a bit special for our 50th year. The SPWLA recognizes the CWLS as an independent body, with common interests amongst all our members; I'd like to see more collaboration between the two societies, especially the DWLS, (Denver Well Logging Society), it's a win-win for all of us in formation evaluation if we do.

In addition, the work of the 2003 executive in collaborating with the CSPG should be continued. Many of our 'clients' are geoscientists and the CSPG provides yet another avenue for the formation evaluation experts in Calgary to share their knowledge and add value to the Industry. I look forward to working with the CSPG to prepare for our next joint conference in 2006.

Web-Based Discussion Forum.

The Society of Core Analysts, SCA, has an excellent approach to technology transfer and problem solving amongst its membership. It's a web-site which includes a topic-based discussion forum for members only. If a member has a technical question, he or she posts it on the website and waits for a response from the other members. This seems to be an excellent method of transferring knowledge within the society – another real value in becoming a member. I'd like to evaluate this in 2005 and will be discussing feasibility with the new executive.

50th Anniversary Lunch.

We plan to recognize our semi-centennial by a special monthly luncheon, probably in May. There was discussion last year about videoing lunches (per the CSPG) and placing them on our web-site for members who cannot make the meetings. This might be a good candidate to try this out!

Challenges Ahead.

No doubt there will be challenges during the year. We continue to struggle with the Palliser. Once again, they have let us down for our planned lunch dates, exercising their prerogative of rebooking to another party 60 days or more from our booked lunch.

Continued on page 4…

Editor's Note

Welcome to the first InSite publication for 2005! We have now made it over half way through what is proving to be a very busy winter drilling season, and with upwards of 580 rigs currently operating in Western Canada, we still have a lot of work ahead of us before breakup.

Unfortunately, our year has not started off the best as far as workplace safety goes, with the loss of two rigs in northern British Colombia alone, one of which came at the cost of life. Incidents such as these emphasize the need for us, as an industry as a whole, to maintain our diligence with respect to workplace safety, and in particular, keeping personnel fully trained and aware of the dangers that can be encountered while working in the oil and gas industry.

With so much happening in the world of oil and gas, 2005 is going to be a year of excitement and change, both within Canada, and internationally. We have seen a growing surge of exploration in the Far East and SE Asia, particularly in India, China, the Gulf of Thailand and throughout the South China Seas as this region attempts to catch its energy supply capabilities up to its usage. India has been openly inviting western companies to come explore it's offshore regions, while also initiating discussions with China, Japan and South Korea, to potentially form a league dubbed the "Organization for Oil Importing Countries". Such strong growth throughout this region will open many doors for Canadian companies looking to expand their horizons. Opportunities like this have been bolstered by a very strong Canadian dollar, and an oil price hovering around the 40-45 dollar mark.

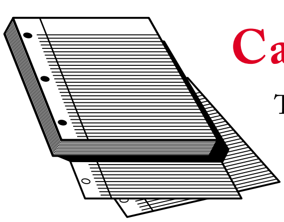
On a note that is closer to home, it has now been over seven years since Canada officially signed the Kyoto Protocol, and on February 16th of this year, this accord becomes international policy. All eyes will be on our now booming sector to see what effect Kyoto implementation will have as Canada progresses forward to our 2010 deadline for our emission reduction targets.

We have two papers in this edition of the InSite. The first, titled "Determination of Connate Water Salinity from Preserved Core" has been provided by Chris Pan at Core Laboratories. The second focuses on improved permeability prediction using hydraulic flow unit concepts and fuzzy logic analysis. This paper is provided by Steve Winstanley, from Anadarko Algeria. Both papers provide a perspective on techniques available to the industry for better understanding our reservoirs, from data and/or core obtained in the field. Also this issue's Tech Corner provides a review of Coal Bed Methane and where it stands at present.

InSite is continually looking for more material and papers to publish. If you have a short paper you wish to submit, or some new technology and/or analysis that you think would be beneficial to the industry, contact information for submittal can be found throughout the magazine, or on the CWLS website (www.cwls.org).

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.

President's Message continued...

They assure us that all other hotels will do the same. The Met Centre is an excellent facility, but the room charge means increased lunch costs. If we are to go this route, we will have to increase lunch charges accordingly. Just one of the challenges for the new executive to overcome!

I'd like to see the excellent initiatives of the last executive continued, especially the Log Graphic Standard Committee, a.k.a "the TIFF committee". This committee, consisting of interested service company members, has produced a format for viewing logs in the digital world, which potentially removes paper logs from the data delivery chain. Excellent progress here, but more work is needed to successfully conclude the initiative.

Finally, if anyone has any ideas or suggestions please don't hesitate to come forward at the lunch meetings – I'll be the guy at the front!

John Nieto, CWLS President.
231-0786
john_nieto@anadarko.com

As The Winch Turns: The Canadian Red Nose Gopher

In mid-summer of 2001 I was driving to a rig located northwest of Lakeside Packers along Trans-Canada Highway #1 near Brooks, Alberta. As I was pulling up to the lease the dirt looked as if it was moving. Upon a closer second look I noticed there was an infestation of gophers. Yes, it was Gopher City! There must have been a gopher hole every step you took and at least 1,000 gophers running around, it was a real Creep Show! Just unbelievable!

As I was rigging up the gas detector the crew was cleaning, washing and painting the rig spotless for the potential buyers who were to arrive the next day. The boys were obviously a little bored and were snaring gophers, painting the little-guys fire engine red and releasing them.

The next day a buyer from Texas toured the bright shiny red rig and was obviously very impressed. The Texan struck up a conversation with the driller near the shale shaker on the mud tanks and noticed a red gopher in the field over yonder. He said in a confused southern drawl "Is that there a red gopher I see?" "Yep, that's a Canadian Red Nosed Gopher.", said the dead-pan faced driller. "No way, it can't be red, that just can't be, you're joshing with me?" The convincing driller said "You don't believe me? Look over there, there's another Red Nose!" and sure enough there was another red gopher and another. The Texan was dropped jawed and totally speechless and finally said "Well I'll be…I never seen such a thing in my entire life, wait until I get back home and tell my friends!"

The driller never let the Texan in on the joke. I wonder if he ever told his friends about the Canadian Red Nosed Gopher?

(No gophers were hurt during the rendition of this story)

Lyall Marshall

Global Santa-Fe's Galaxy II Jack-up Platform in the Halifax harbor, January 2004. Two of the jack-up towers (foreground) and in the drilling rig (center background) are visible. The platform can operate in a maximum water depth of 110m.

Photo Courtesy of the Bercha Group

CWLS 2005 to 2006 Executive

President

John Nieto
Anadarko
425 – 1st Street SW
Box 2595, Stn M
Calgary, AB T2P 4V4

403-231-0276 (Office)
403-669-0786 (Cellular)
403-231-0463 (Fax)
john_nieto@anadarko.com

Past President

Jeff Levack
Tucker Wireline Services
900, 444 – 5th Avenue SW
Calgary, AB T2P 2T8

403-232-1705 (Office)
403-804-6679 (Cellular)
403-264-2118 (Fax)
jlevack@tuckerenergy.com

Vice-President

Ken Faurschou
Schlumberger
525 – 3rd Avenue SW
Calgary, AB T2P 0G4

403-509-4073 (Office)
403-540-9998 (Cellular)
403-509-4025 (Fax)
faurschouk@slb.com

Secretary

Carley Gyori
Baker Atlas
1000, 401 – 9th Avene SW
Calgary, AB T2P 3C5

403-537-3530 (Office)
403-537-3767 (Fax)
carley.gyori@bakeratlas.com

Treasurer

Gary Drebit
Schlumberger of Canada
525 – 3rd Avenue SW
Calgary, AB T2P 0G4

403-509-4267 (Office)
403-509-4220 (Fax)
gdrebit@calgary.oilfield.slb.com

Publications Co-Chair

Ben Urlwin
Waveform Energy Ltd.
Petro-Canada Centre, West Tower
Suite 3000, 150 – 6th Avenue S.W.
Calgary, AB T2P 3Y7

403-538-2185 (Office)
403-538-2122 (Fax)
403- 813-0592 (Cellular)
ben@waveformenergy.com

Publications Co-Chair

Robert Bercha
Anadarko
425 – 1st Street SW
Box 2595, Stn M
Calgary, AB T2P 4V4

403-231-0249 (Office)
403-512-9446 (Cellular)
403-231-0463 (Fax)
robert_bercha@anadarko.com

Chair of Committees

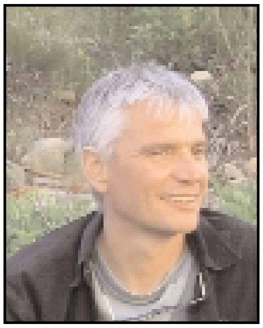
Richard Bishop
Precision Wireline
Suite 500, 5th Avenue SW
Calgary, AB T2P 3L5

403-218-6847 (Office)
403-818-9437 (Cellular)
403-237-5480 (Fax)
rbishop@precisionwireline.com

Membership Chair

Dion Lobreau
Mancal Energy Inc.
1600, 530 – 8th Avenue SW
Calgary, AB T2P 5G2

403-231-7673 (Office)
403-231-7679 (Fax)
dlobreau@mancal.com



Message from the Past President

One of the key duties of the CWLS Past President is to put together the slate of candidates for the next Executive elections. My goal is to have two candidates lined up for each position before July of this year. Here are some reasons to say "yes" when I ask you to accept a nomination:

- Anything the CWLS does only happens because of the efforts of volunteers. If you never contribute you are living off the energy of others. Paying for a lunch ticket doesn't make the lunch happen. That just covers the food and room. The Executive and the speakers make it happen.
- You can earn APEGGA professional development points.
- You can develop a skill that your current job doesn't expose you to but that future jobs might require.
- You get to meet interesting industry people that you might never have met otherwise.

The positions available on the Executive are:

- President (must have previously served on the Executive)
- Vice-President
- Chair of Committees
- Publications Co-Chair
- Treasurer
- Membership Chair
- Secretary

When you decide to put yourself up for nomination or if you have any questions please contact me. New members are encouraged to participate.

Jeff Levack
804-6679
jlevack@tuckerenergy.com

New Members

David Newman: McDanial & Associates
Peter Okeke: BP Canada
John Perrin: Schlumberger
Bryce Breuning: Baker Atlas
Nicole Wilson: Student
Gene Sherba: Encana
Randy Evans: Anadarko
Chris Miller: Swift Energy
Randy Maksymowich:
Jon Sliwinski: Tucker Energy Services

Members on the Move…

Winston Karel (Burlington from BP)

Mark Paddison (Anadarko from Continental Labs)

John Stroud (Oracle Energy from JDS Consulting)

Steven Dixon (Cresent Point from Dominon Energy)

Satwan Diocee (Talisman Energy from Precision Wireline)

Eric Pickle(Exceed Energy from Diaz Energy)

Membership Update: Membership on-line should be completed by the end of March. A big thank you to everyone that responded to my e-mail on when people actually joined the CWLS in order to make the membership number more acurate.

Dion R. Lobreau
CWLS Membership Chairman

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

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

Determination of Connate Water Salinity of Tight Gas Reservoirs Using Preserved Core

Chris Pan
Core Laboratories Canada Ltd., Calgary, Alberta, CANADA
2810 – 12th Street, NE, Calgary, Alberta T2E 7P7
(chris.pan@corelab.com, phone: 250-4077; fax: 250-4064)

Abstract:

One of the parameters needed to calculate in-situ water saturation from wireline logs is the resistivity of connate water, R_w. It is usually determined by measuring the resistivity and chemical composition of uncontaminated connate water produced from the formation or underlying aquifer. If the formation does not produce any connate water, e.g., Deep Basin plays in Western Canada and tight gas reservoirs, or the produced water is contaminated it is difficult to determine an accurate R_w value necessary for water saturation calculation. This paper presents the results of a laboratory study of examining the validity of core based salinity determination. Controlled experiments were conducted on core samples, one Berea sandstone core, one tight sandstone core and one tight carbonate core with the latter two coming from gas producing formations in Alberta. The air permeability of the samples varies from 1 mD to 80 mD. Standard sandstone brine and carbonate brine of known salinity and compositions were used as the base fluids for comparison in the tests. Several methods, i.e., electrical properties measurement (back calculating R_w), de-ionized water flow through extraction, methanol flow through extraction, and extraction of core salts by leaching ground core, are compared and the pros and cons of each method are discussed. All of the methods tested in the study provided reasonably good results for the sandstone samples with little soluble minerals but poor results for the carbonate sample due to soluble minerals in the matrix. The effect of dissolution of soluble minerals on extracted salinity and individual ion concentrations are evaluated.

Introduction

One of the parameters needed to calculate in-situ water saturation from wireline logs is the resistivity of connate water, R_w. It is usually determined by measuring the resistivity and chemical composition of uncontaminated connate water produced from the formation or underline aquifer. Log analysis using SP logs and interpretation from porosity and resistivity logs in aquifer are other possible sources of R_w values. If the formation does not produce any connate water, e.g., deep basin plays in Western Canada and tight gas reservoirs, or the produced water is contaminated it is difficult to determine accurate R_w necessary for water saturation calculation. Difficulty also arises if the salinity of connate water in a reservoir is not constant, leading to vertical and/or areal variation in R_w in the reservoir (McCoy, et al, 1994; Rathmell, et al., 1995; Rathmell, et al. 1999). In these cases core based salinity measurement provides an alternative and, sometimes, the only method to determine the R_w values.

Accurate measurements of core water salinity are based on the assumption that all of the chemical ions in connate water at reservoir conditions are still contained and remained the same in the core water at ambient conditions at surface. If the formation water is not at or near the solubility limits, i.e., soluble at reservoir temperature and pressure but insoluble at ambient conditions, it is possible to cut cores that retain in-situ formation water compositions by low invasion coring technology and oil based mud (OBM). Field examples have been documented that properly designed OBM coring procedures do not alter in-situ water content or brine composition of reservoir interval with immobile water saturation (Richardson, et al., 1994; Woodhouse, 1998). Most tight gas reservoirs do not produce formation water and usually there is no underline aquifer, which makes it difficult to determine the R_w necessary for water saturation calculation. Because of the low mobility of formation water in tight gas reservoirs it is possible to use OBM core to determine both connate water saturation and salinity. An example was given by Nagra et al. (1982) who used OBM cores to determine connate water salinity of a Deep Basin tight gas reservoir in Western Canada. Other examples of core based salinity determination include those by McCoy et al. (1994), Rathmell et al. (1995) and Rathmell et al. (1999), covering both conventional gas and oil reservoirs. Given the limited documented successful applications of core based salinity determination, this technique remains to be recognized as an alternative to more traditional methods.

Core based salinity determination has been included in Recommended Practices for Core Analysis by American Petroleum Institute (API RP40, 1998). There are two methods recommended by API. One is direct core water recovery the other is water extraction of core salts. The first method requires mechanically expelling connate water out of preserved core either using an immiscible fluid flush or by centrifugation. This

Continued on page 9…

Determination … continued from page 8

method is applicable for core samples containing mobile brine saturation, which can be reduced by viscous immiscible fluid flow or centrifugation, e.g., core from water or hydrocarbon-water transition zone. It is not suitable for tight rock reservoirs or core from zones with immobile water saturation.

In most cases, especially for tight gas reservoirs, the method of water extraction of core salts is the only viable choice. This method is also called commutation analysis (Newsham and Rushing, 2002). A preserved core sample with connate water still in the pore space is first Dean-Starked to determine the volume of pore water. The sample, with precipitated salts left in the pore space after Dean Stark and oven drying, is ground in a mortar to about 16-mesh size. Known volume of deionized water is added to the sample and the mixture is stirred to allow the salts to re-dissolve in the added water. The salt solution is extracted by filtering and centrifuging the mixture, and saved for salinity determination. The salinity of the extracted water is determined by i) chemical titration of chloride ion, ii) standard water analysis of concentrations of major cations and anions, and iii) resistivity measurement. The reason for using chloride is that this ion contributes most to R_w and is less sensitive to dissolution of soluble components in the core during the extraction processes. The salinity is usually expressed as parts of sodium chloride per million parts of core water. Core water salinity, in terms of sodium chloride concentration, is back calculated by the following equation,

$$\text{Salinity of core water (mg NaCl/kg core water)} = \frac{\text{NaCl (mg)}}{[\text{core water (gm)} + \text{NaCl (gm)}]} \times 1000 \qquad (1)$$

in which *NaCl* weight is determined from measured Cl^- concentration and the volume of the distilled water used for the extraction. Core water weight is determined from Dean Stark analysis.

One potential error of salt extraction method is that core material containing soluble minerals, such as anhydrite and halite, in rock matrix not in direct contact with pore water, may release ions during extraction. In addition, sulfide minerals such as pyrite, may be oxidized to release soluble ion sulfate salts. In these cases the extrapolated salinity or ion concentrations are likely to be overstated as a result of dissolution of soluble minerals.

All of the published papers on core based salinity determination are field case studies. No laboratory study has been documented to systematically evaluate the validity of this method. This paper presents the results of a laboratory study of controlled experiments on three core samples, i.e., one Berea sandstone sample, one tight sandstone sample and one tight carbonate sample with the latter two coming from gas producing formations in Alberta. The objectives of the study are i) to examine the validity of core based salinity determination through controlled experiments, ii) to compare several laboratory methods, i.e., electrical properties measurement (back calculating R_W), de-ionized water flow through extraction, methanol flow through extraction, and extraction of core salts by leaching ground core, and iii) to study the contribution of soluble components in rock matrix to the salinity and individual ion concentrations in solution.

Experimental Procedures

The laboratory experiments were designed to investigate whether the core water resistivity, R_W, or salinity could be back calculated from either resistivity measurement or various extraction methods. Core samples with known immobile brine saturation of known salinity were measured for resistivity and extracted using a known volume of de-ionized water or methanol. The results of back calculated R_W, total salinity and ion concentrations are compared with the know values, respectively. Details of the experimental procedures and sequence of the tests are given below.

Core Sample and Fluid Preparation

Three core samples were selected for the study, one Berea sandstone sample, one tight sandstone sample and a tight carbonate sample. The samples were cleaned in toluene and methanol to remove any hydrocarbon and salts left in the pore space. Standard ambient porosity and air permeability were measured after oven drying and thin sections were made from the end trims of the samples.

Standard sandstone (SS) brine of 124,130 mg/kg salinity was prepared for testing on the two sandstone samples. Standard carbonate (CB) brine of 157,729 mg/kg salinity was made for testing on the carbonate sample. Both brines were prepared from reagent grade chemicals and de-ionized water. The compositions of the brines are presented in Table 1.

Continued on page 10…

Determination … *continued from page 9*

Table 1. Composition of brines used in the tests

Ion	Standard SS Brine, meq/L	Standard CB Brine, meq/L
Na^+	1238	2165
K^+	325	0.0
Ca^{++}	420	28
Mg^{++}	0.0	1.3
Cl^-	2100	6.8
SO_4^{--}	4.0	2140

Flow Through Extraction, Dry Samples

The core samples were vacuum and pressure saturated with respective brines, i.e., sandstone samples with the standard sandstone brine and carbonate sample with the standard carbonate brine. Formation resistivity factor, FF, was measured for each sample from which the cementation exponent, m, was calculated. The samples were then desaturated by porous plate in five incremental capillary pressures up to 1380 kPa and resistivity index, RI, at each saturation was measured from which the saturation exponent, n, was determined for each sample. The final water saturation (or volume of water) of each sample was determined by Dean Stark using toluene.

After Dean Stark the samples were loaded in core holders individually and de-ionized water was flowed through each sample against a backpressure of 1380 kPa to facilitate saturation in the sample. The flow was continued until the effluent was salt free (checked by silver nitrate) or a minimum of 20 pore-volume throughputs. The effluent was collected and analyzed for standard water analysis. Cations were measured by Inductive Coupled Plasma (ICP) and anions by Ion Chromatography (IP). Salinity of the brine or specific ion concentration in each sample was back-calculated based on the original water volume in the sample determined by Dean Stark and the extracted salts weight measured from the effluent using the following equation,

$$S_{core}\ (mg/kg\ of\ corewater) = \frac{W\ (mg)}{[DS\ Core\ Water\ (gm) + Extracted\ Salt\ Weight\ (gm)]} \times 1000 \quad (2)$$

in which S_{core} is the back calculated salinity in terms of total dissolved solids of the brine or individual cation or anion concentration in mg/kg (ppm), *W* is the total weight of extracted salts or weight of each cation or anion in mg, depending on what S_{core} represents, *Extracted Salt Weight* is the total weight of the extracted salts in *gm*.

R_w by Electrical Properties

The same samples were dried and porosity of each sample, ϕ, was re-measured. After re-saturation with respective brines, the samples were desaturated in a centrifuge to immobile water saturations close to those obtained by the porous plate. Final water saturation of each sample, S_w, was confirmed by the weight after centrifugation. True resistivity, R_t, of each sample was measured and used to back calculate R_w of the brine from the transformed Archie's equation below,

$$R_W = R_t \phi^m S_W^n \quad (3)$$

in which *m* and *n* are cementation and saturation exponents of each sample measured before. The back-calculated R_w values of the brine in the samples should be close to the known values of the saturating brine.

Flow Through Extraction, Wet Samples

After resistivity measurements, and with known volumes of brine still in them, the samples were loaded in core holders individually and methanol was flowed through each sample against a backpressure of 1380 kPa. The flow was continued until the effluent was salt free (checked by silver nitrate) or a minimum of 20 pore-volume throughputs. The effluent was collected and analyzed for standard water analysis. The salinity and ion concentrations of the brine in the samples were back calculated using equation (2).

In application methanol extraction is preferred as it can minimize the potential dissolution of minerals that may become soluble in water. The methanol extraction removes both water and salts. The solution is then analyzed for water and ion concentration.

Extraction of Salts, Ground Core

This is the most common method of core based salinity determination as it is fast and requires the least amount of equipment. However, it is destructive thus the last one in the sequence of this laboratory investigation.

Continued on page 11…

Determination … *continued from page 10*

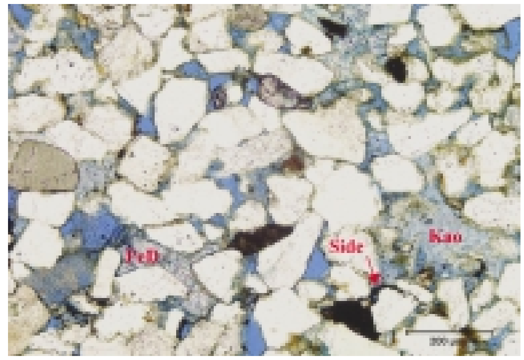
After the flow through extraction in the previous step the samples were dried and pore volumes were re-measured. They were re-saturated with respective brines and desaturated using centrifuge to immobile water saturation. Resistivity of each sample, R_t, was measured again for R_w back calculation. Each sample was then Dean-Starked in toluene and water coming out of the sample was collected and measured. After drying in an oven, the sample was crushed to approximately 16-mesh size and weighed and transferred to a flask. Enough de-ionized water was added to just cover the ground sample. The mixture was stirred vigorously for several minutes and left soaking overnight. The solution was extracted by filtration and centrifugation and saved for standard water analysis. The same equation (2) was used to calculate the core brine salinity.

Sample Properties

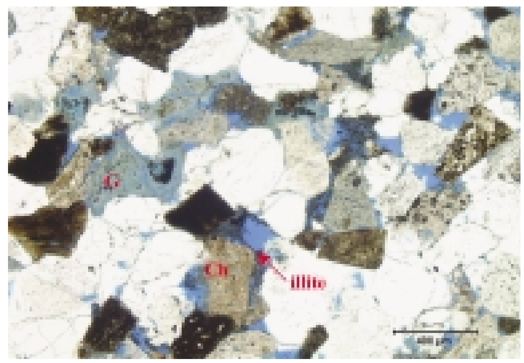
The routine properties of porosity, air permeability and grain density of the three core samples are given in Table 1. Archie parameters, m and n, were measured as described in the above procedures and are included in the table, together with the brine used for each sample. The Archie parameters are used for R_w back calculation.

Both sandstone and carbonate rocks were selected in order to investigate the influence of differences in mineralogy on the effectiveness of core based salinity analysis. Petrographic thin sections were prepared from the end trims of the actual samples to study the framework and diagenetic composition, and to identify any potential soluble minerals. Thin section photographs of the three samples are shown in Figure 1.

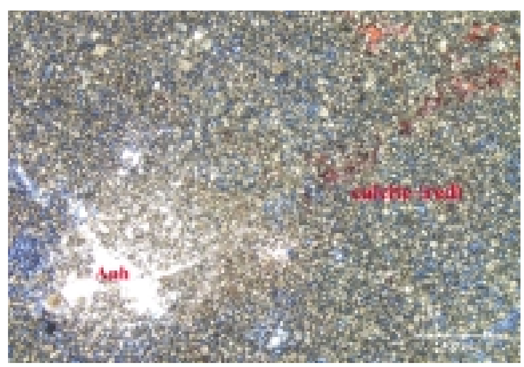
The Berea Sandstone is quartzose, with a grain framework consisting dominantly of quartz grains with minor amount of chert and dolomite grains. Ferroan dolomite and siderite are found as cement bounding the quartz grains. Authigenic clay minerals include kaolinite and chlorite, filling some pores and lining



a) Berea Sandstone



b) Tight Sandstone



c) Tight Carbonate

Figure 1.
Thin Section Photographs of the Core Samples

Table 2 Properties of the core samples and brines used

Sample	Porosity %	Air permeability mD	Grain density kg/m3	Cementation Exponent, m	Saturation Exponent, n	Brine
Berea sandstone	18.6	76.8	2680	1.76	1.47	Standard SS brine
Tight sandstone	11.4	1.34	2650	1.90	2.43	Standard SS brine
Tight carbonate	17.5	1.80	2820	1.92	1.79	Standard CB brine

Continued on page 12…

Determination … continued from page 11

quartz grains. The tight sandstone sample is more argillaceous, containing quartz, glauconite, and chert grains, with quartz overgrowths as the main cement. Ferroan dolomite and siderite are found as replacive phases, not cement. Illite is the main authigenic clay found filling pore space and lining grain surfaces. The pore system is dominated by micro pores remaining after precipitation of quartz overgrowths and clays, plus chert compaction, with a small amount of intergranular macro pores. The carbonate sample is a dolostone dominated by intercrystalline pores with minor mineralized fractures. The main cement is anhydrite with minor calcite.

Results and Discussion

R_w by Electrical Properties

The true resistivity values, R_t, of the samples partially saturated with respective brines were measured and, with known water saturation, the R_w of the brine in each sample is calculated using equation (3). To check reproducibility, the measurements were repeated on the same three samples at different stages of the experiments and with different brine saturation each time. The values of the back-calculated R_w are plotted against the measured R_w of the standard brine as shown in Figure 2.

The back-calculated R_w values of the sandstone samples are in good agreement with the measured R_w of the standard sandstone brine, indicating the method is valid for the sandstone samples. However, the back-calculated R_w values of the carbonate sample are lower than the measured R_w of the standard carbonate brine, implying that the brine in the carbonate sample had higher salinity than the standard carbonate brine introduced into the sample.

As long as a core retains formation brine not contaminated by coring fluid or evaporation, e.g., preserved low invasion OBM core, the resistivity of the formation brine can be back calculated using the method introduced above. The procedures would be as follow: i) First drill a number of small plugs from the center of preserved core using mineral oil, core preservation by freezing is not recommended as a salinity front develops as the core freezes which concentrates salts ahead of the freeze line (API RP 40); ii) measure R_t for each sample; iii) Dean Stark to determine S_w for each sample; iv) clean the samples free of salts, measure porosity and Archie's parameters (*m* and *n*) using NaCl brine with estimated formation R_w; v) back calculate R_w from equation (3). For application in clean formations, i.e., no conductive minerals such as clays, Archie's parameters are independent of brine salinity. No correction is necessary. If the formation rock contains clays, Archie's parameters are dependent on brine salinity, and equation (3) is no longer valid. The following equations from Waxman and Smits shaly sand model (Waxman and Smits, 1968) can be used for R_w back calculation,

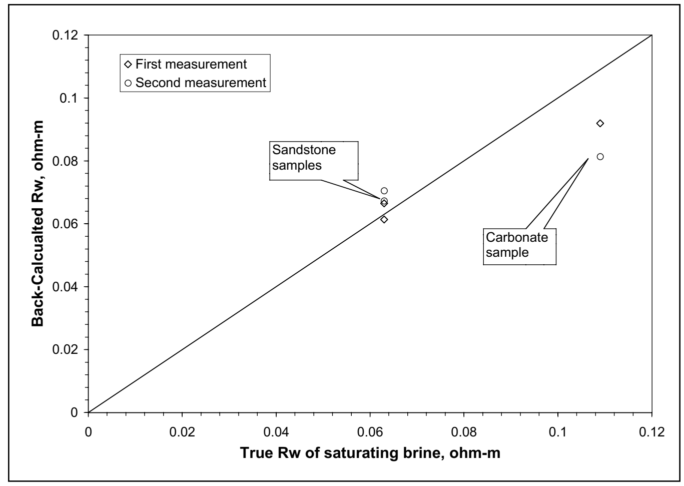


Figure 2. Comparison of the back calculated Rw and the measured Rw of the saturating brines

$$R_{we} = R_t \phi^{m^*} S_w^{n^*} / a^* \tag{4}$$

$$R_w = \frac{R_{we}}{1 - R_{we} B Q_v / S_w} \tag{5}$$

in which *m** and *n** are corrected cementation, saturation exponents, respectively, which are pore geometry factors not dependent on salinity. Q_v is cation exchange capacity per unit pore volume. B is counter ion conductance as define by Waxman and Smits (1968). More recently Dacy provided a generalized equation for B calculation at any temperature (Dacy, 2003).

Results From the Extraction Tests

The results of the three different extraction methods are presented in Table 3, showing the back-calculated salinity in terms of total dissolved solids for each sample, together with the standard brine saturation. The salinity values of the extracted brine from both sandstone samples are in good agreement with that of the standard sandstone brine for all of the three methods, which is consistent with the result of the R_w method introduced above. The results of Berea Sandstone sample are generally better than those of the tight sandstone sample.

On the other hand, the results of the carbonate sample are far from satisfactory. The extracted brine of the carbonate sample

Continued on page 13…

Determination … continued from page 12

Table 3. Results of back calculated salinity in terms of total dissolved salts from various extraction tests

	Sandstone Samples, mg/kg			Carbonate Sample, mg/kg	
Extraction Method	**Standard SS Brine**	**Berea SS**	**Tight sandstone**	**Standard CB Brine**	**Tight carbonate**
Flow through extraction, dry	124,130	121,712	172,199	157,729	264,592
Flow through extraction, wet	124,130	136,229	140,727	157,729	342,004
Extraction of salts, ground	124,130	122,620	122,355	157,729	169,457

had a much higher salinity than the standard carbonate brine. The result from the back calculated R_W also indicates the brine in the pore space of the carbonate sample was more saline than the standard carbonate brine (Figure 2), implying that there was dissolution of excessive salts into the brine. An examination of the thin section of the carbonate sample, Figure 1(c), confirms the possibility of dissolution. There is uneven distribution of anhydrite cement ($CaSO_4$) in the pore space, which readily dissolves in unsaturated aqueous solution. Although the standard carbonate brine has high salinity, it is far from being saturated. It is noted that the salinity of the extracted carbonate brine decreased significantly from a high of 342,004 ppm (mg/kg) to 169,457 ppm. This was attributed to removal of the anhydrite by the flow through cleaning of de-ionized water and methanol in the steps prior to the last extraction test in which the low salinity measurement was obtained.

In addition to total dissolved solids, cation and anion concentrations in the extracted solutions were also measured and then used to back calculate the concentrations in the original core brine. The results are presented in Figures 3 to 7.

The flow through extraction of the sandstone samples after Dean Stark produced slightly more cations, i.e., Na^+, K^+, Ca^{+2} and Mg^{+2}, and sulfate anion, $SO4^{-2}$, but less chloride, Cl^-, than those in the standard sandstone brine, as shown in figure 3. The increase is more for the tight sandstone sample than the Berea sample. Being quartzose sandstone, the Berea sample does not contain as many minerals as the tight sandstone sample other than quartz. The much-elevated sulfate reading from the tight sandstone sample strongly indicates that there were sulfide minerals in it which oxidized releasing excess of cations and sulfate anions in extracted solution. The relatively low reading of chloride, however, indicates that the flow through process on the dry samples might not be effective in removing all of the precipitated salts left in pore pace by Dean Stark. De-ionized water removed the salts that came in contact with it but could not do so in pores that were not invaded by the water. Flowing water through a dry sample, even with backpressure, does not saturate all of the pores but bypasses inaccessible ones. Therefore the flow through extraction method is potentially not effective on dry sample unless saturation is easy to achieve, such as in high quality sample (homogeneous and good permeability).

The results of methanol flow through extraction of the wet sandstone samples (with know brine saturation) are more encouraging as shown in Figure 4. The chloride readings of both samples are close to the known chloride concentration in the sandstone brine. Although still higher than the original values, the concentrations of the extracted cations (except Na^+) and sulfate ions are lower than those of the dry extraction.

The back calculated ion concentrations of the flow through extraction of the carbonate sample are much higher than the original values of the standard carbonate brine introduced into the sample, especially the Ca^{+2} and $SO4^{-2}$ ions, as shown in Figure 5. There was little calcium in the original carbonate brine and the concentration of calcium in the extracted brine was over 1000 times higher from the flow through extraction of the dry sample and 2000 times higher from the wet sample. Similarly as much as twice the amount of sulfate was measured from the flow through extraction of the wet sample compared to the original sulfate content in the carbonate brine. It is certain that the anhydrite mineral in the matrix framework was dissolving and extracted by the flow through processes. The flow through extraction of the wet sample yielded higher ion concentration than the dry sample for the same reason that water did not have access to some tight spots with anhydrite in the dry sample, whereas those spots became accessible in the wet sample.

Core salt extraction from ground sample is the most common and economic method for core based salinity determination. It was included in this laboratory study as the last method investigated since it is destructive. The results of the sandstone samples are presented in Figure 6 and that of the carbonate in

Continued on page 14…

Determination … *continued from page 13*

Figure 7. The extracted ion concentrations of both sandstone samples are in good agreement with the values of the standard sandstone brine. The apparently good match indicates the extraction was successful. The most significant change happened in the carbonate sample. Although the calcium reading was still a little high, the sulfate concentration dropped remarkably close to the standard value. The improvement might be attributed to the sample having been flow through cleaned twice before this step. A large amount of soluble components, one of them being anhydrite, had already been removed in the previous steps, leaving minor volumes of soluble minerals for further dissolution. The same improvement was also evident in the result of the tight sandstone.

Dissolution of solid minerals in rock matrix can be divided into two types. One is direct dissolution at large water/rock ratio such as anhydrite, as we have demonstrated in this study. The other is oxidation dissolution, which applies to those minerals insoluble in an anaerobic environment, but soluble after oxidation. Sulfide minerals such as pyrite belong to this group. The oxidation of pyrite releases sulfate salts, which not only elevate the sulfate level, but increase concentrations of cations such as sodium, calcium and magnesium, due to an acidic environment created by the release of sulfate ions (Rathmell, et al., 1995). Chloride, however, is not affected by this mechanism. A comparison of the chloride concentrations of the sandstone samples from different extraction methods is given in Figure 8. Except in flow through extraction of the dry samples, the chloride concentrations from the other two methods are very close to that of the standard sandstone brine, confirming the validity of using chloride as the least affected ion in an extraction process.

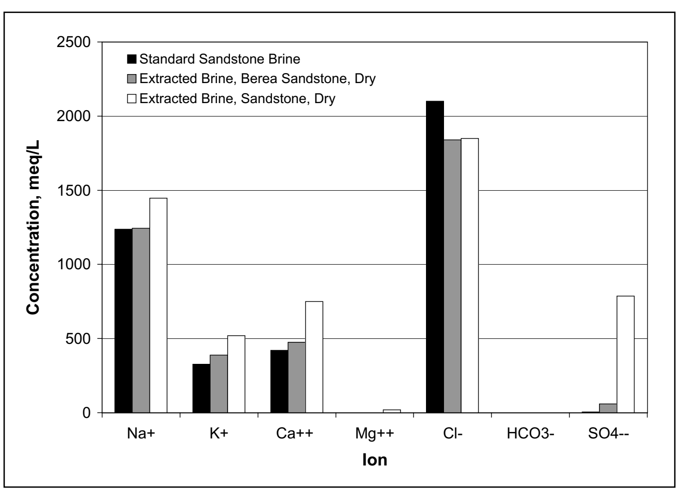


Figure 3. Ion concentrations from flow through extraction of sandstone samples after Dean Stark and drying

In summary, all of the methods tested in the study provided reasonably good results from the sandstone samples, which have little soluble minerals, but a poor match for the carbonate sample, due to soluble minerals in the framework of the sample. There is no clear winner among the methods tested in this study. The good results obtained from the extraction of core salts from the ground samples were influenced positively by the flow through cleaning steps prior to the test. The best practice is to not rely on just one method, but use a combination of two tests to check reproducibility. For example, instead of just using

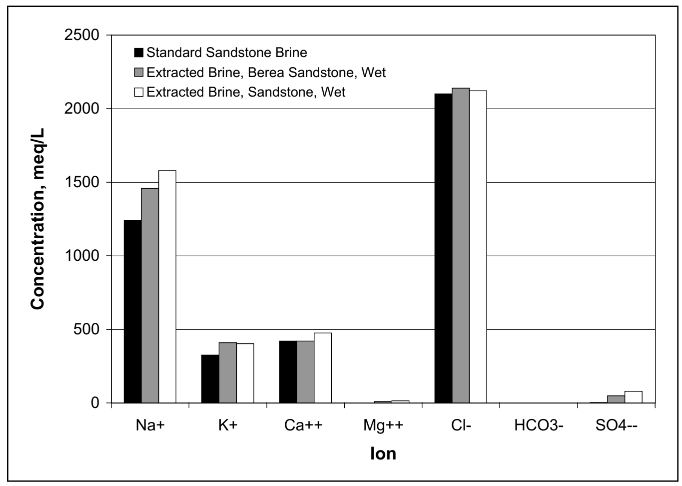


Figure 4. Ion concentrations from flow through extraction of sandstone samples with known brine saturation

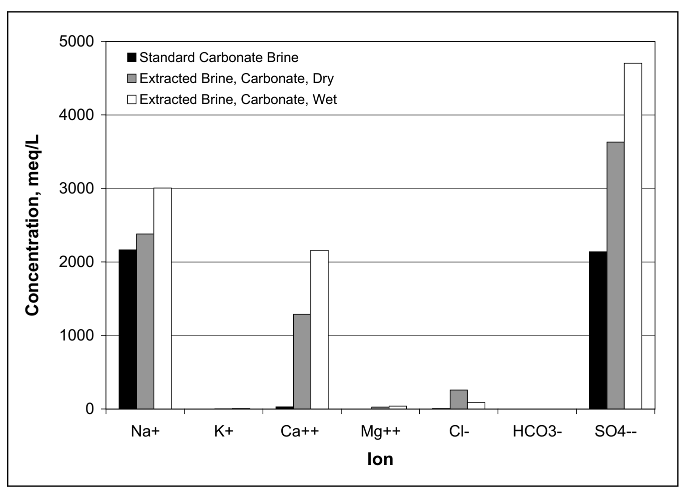


Figure 5. Ion concentrations from flow through extraction of carbonate sample, both after Dean Stark and drying and with known brine saturation

Continued on page 15…

Determination ... *continued from page 14*

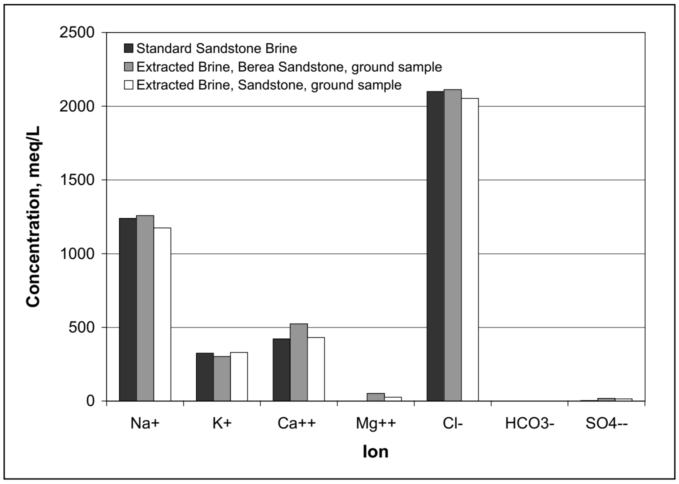


Figure 6. Ion concentrations from extraction of core salts of ground sandstone samples after Dean Stark and drying

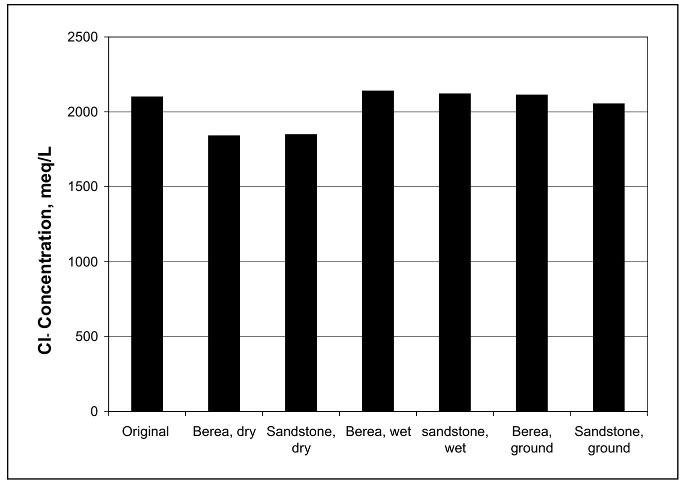


Figure 8. Chloride concentrations of sandstone samples from all three tests

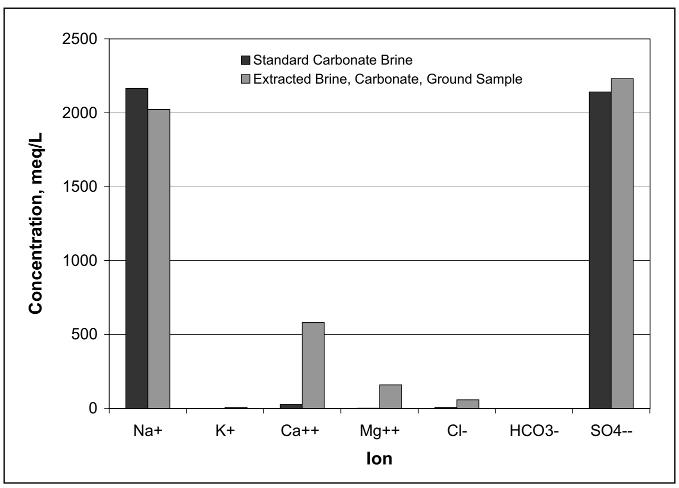


Figure 7. Ion concentrations from extraction of core salts of ground carbonate sample after Dean Stark and drying

the method of core salt extraction from ground sample one can choose to use it together with flow through extraction or back calculation of R_W from electrical resistivity measurement.

Low Invasion Coring

It has been demonstrated that the extraction of core salts is effective as long as there are not significant volumes of soluble minerals in the sample. However, the extracted salinity obtained by this method is valid only if the brine in a core is representative of the formation brine. Studies have proven that low invasion coring techniques, together with carefully designed oil based mud can retain uncontaminated formation brine in core (Richardson, et al., 1994; Woodhouse, 1998). Successful low invasion coring requires the following equipment and procedures (Rathmell, et al., 1995):

1. Parabolic, low invasion core bit design.
2. High weight-on-bit and rotary speed to maximize coring rate. Coring rate must exceed beneath-the-bit spurt velocity for the mud.
3. Minimize high temperature-high pressure static fluid-loss and spurt velocity
4. Core plugs cut within 24 hours after the core arrives at the surface.

The best coring fluid is "water-free" synthetic oil-based low invasion fluid. If a more conventional oil-based mud is preferable, the following requirements should be maintained (Rathmell, et al, 1995):

1. A low spurt loss capability, i.e., quickly build a very low permeability filter cake to limit invasion.
2. A HTHP fluid loss value of 4 to 6 cc, or less.
3. A maximum water content of 5% by volume, with a preference for < 2%.
4. At least 100 lb/bbl of very fine (3 to 10 micron median size) calcium carbonate as pore bridging media.
5. A filtrate/formation brine interfacial tension (IFT) of at least 7 dynes/cm, and preferably >12 dynes/cm.

Continued on page 16...

Determination … *continued from page 15*

6. Excess lime >1.0 lb/bbl.
7. An electrical stability (ES) of >2000 volts, to ensure a tight emulsion with no water moving through the filter cake.

A heat stable oil-soluble tracer may help to track and quantify the amount of filtrate invasion. Special attention should be given to item 5 with respect to IFT between filtrate and formation brine. Even if connate water saturation is immobile in a formation, this immobility of the formation water is defined by capillarity equilibrium in the fluid-rock system. Thus it is relative to the fluid in contact with the water. For example, in a gas reservoir the connate water is at immobile saturation in equilibrium with the in-situ gas. The IFT between gas and connate water is 50 dynes/cm. If the filtrate invading the core has a low IFT (<7 dynes/cm) with the connate water the capillary equilibrium between gas and the water is broken, and the water may become mobile and flushed out by the filtrate. Therefore, careful design of coring programs is essential for the success of core based formation saturation and salinity determination.

Conclusions

1. Core based salinity determination is valid as long as the core does not have significant volumes of soluble minerals.
2. All four methods, i.e., Rw from resistivity measurement, water flow through extraction, methanol flow through extraction and extraction of core salts from ground sample, provided reasonably good results for the sandstone samples (which have low volumes of soluble minerals), but poor results for the carbonate sample, due to soluble minerals in the framework.
3. Soluble minerals affecting the extraction results included anhydrite and sulfide minerals such as pyrite. As a result of mineral dissolution, concentrations of sodium, potassium, calcium, magnesium and sulfate were overstated.
4. Chloride concentration was stable and not significantly affected by the dissolution processes.

Acknowledgements

The author would like to thank Core Laboratories Canada Ltd. for permission to publish this work. Thanks to Alvaro Patino and Raymond Chan for the excellent job of conducting the laboratory tests, Richard Thom for careful review of the paper, and Don Harville, Tracey Henselwood for stimulating discussion and cooperation.

References

Dacy, J., "An Improved and Unifying Empirical Equation for B, Counterion Conductance", Presented at the SPWLA Spring Topical Conference, Taos, NM, March 30 – April 3, 2003.

Exploration and Production Department, API, "Recommended Practices for Core Analysis – Recommended Practice 40", Second Edition, Feb. 1998.

McCoy, D.D., Warner, H.R., and Fisher, T.E., "Water Salinity Variations in the Ivishak and Sag River Reservoirs, Prudhoe Bay Field", SPE 28577, Presented at the SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, Sept. 25-28, 1994.

Nagra, S.S., Nelson, H.W., and Gordon, H.M., "Interpretation of Water Salinities Obtained from Oil Base Cores in the Deep Basin of Western Canada", Paper No. 82-33-53, Presented at the 33rd Annual Technical Meeting of the Petroleum Society of CIM, Calgary, Alberta, June 6-9, 1982.

Newsham, K.E. and Rushing, J.A., "Laboratory and Field Observations of an Apparent Sub Capillary-Equilibrium Water Saturation Distribution in a Tight Gas Sand Reservoir", SPE 75710, Presented at the SPE Gas Technology Symposium, Calgary, Alberta, Apr. 30 – May 2, 2002.

Rathmell, J.J., Atkins, L.K., and Kralik, J.G., "Application of Low Invasion Coring and Outcrop Studies to Reservoir Development Planning for the Villano Field", Presented at the 6th Latin American and Caribbean Petroleum Engineering Conference, Caracas, Venezuela, Apr. 21-23, 1999.

Rathmell, J.J., Bloys, J.B., Bulling, T.P., Parr, J.J., Pasternack, E.S., Jerauld, G.R., and Sakurai, S., "Low Invasion, Synthetic Oil-Base Mud Coring in the Yacheng 13-1 Gas Reservoir for Gas-in-Place Calculation", SPE 29985, Presented at the International Meeting on Petroleum Engineering, Beijing, PR China, Nov. 14-17, 1995.

Richardson, J.G., Holstein, E.D., Rathmell, J.J., and Warner, H.R., "Investigation of As-Received Oil-base-Core Water Saturations from the Ivishak Reservoir, Brudhoe Bay Field", SPE 28592, Presented at the SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, Sept. 25-28, 1994.

Waxman, M.H. and Smits, L.J.M., "Electrical Conductivities in Oil-Bearing Shaly Sands", SPE 1863-A, SPEJ, June 1968, P. 107-122.

Continued on page 17…

Determination *… continued from page 16*

About the Author

Chris Pan is supervisor of Advanced Rock Properties of Core Laboratories Canada Ltd. He has four years of experience in special core analysis with emphasis on using core data for enhanced reservoir description, production optimization/reservoir management, producing problem solving, and interdisciplinary integration. Prior to this, Chris worked with Imperial Oil on Cold Lake project and with Petroleum Recovery Institute on multiphase flow in fractured media. He holds a Ph.D. degree in engineering from the University of Calgary and an engineering degree from Wuhan University of Technology in China. He is a member of CWLS, the Petroleum Society of CIM and SCA.

One Format for Well Log Graphic Files

The Canadian Well Logging Society (CWLS) has developed a recommended format for digital log graphics.

For several years now people have been using, sharing and archiving digital images of logs. This has not been as easy as it could be because there is such a wide variety of file formats in use. To encourage greater standardization, the CWLS has worked with industry to define a recommended format for log graphic files. Logging companies and data vendors may continue to provide images in whatever format best serves their clients. But, if an individual, company or government group wishes to receive, manipulate or store a single file format, they can now specify the "CWLS Format".

This file format is:

- Group 4 TIFF containing all tags required for a baseline TIFF
- Minimum resolution of 200 dpi
- Orientation = Top left

If you wish to test the compatibility of your log viewing software with this format, example files from each logging company are available on the CWLS website at www.cwls.org.

Calgary Well Log Seminars 2005

by Professional Log Evaluation and W.D.M.(Bill) Smith P.Geol.

Register at 403 265-3544

UNDERSTANDING WELL LOGS
May 30, October 3

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

Fee is $350 + GST

BASIC WELL LOG SEMINAR
May 25-27, October 5-7

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

Fee $1100+GST

INTERMEDIATE WELL LOG SEMINAR
April 18-20

In conjunction with the CIMM. Call Gerry at the CIMM to register at 237-5112.

INTERMEDIATE WELL LOG SEMINAR
June 1-3, Oct. 12-14

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

Fee $1290+GST

Annual General Meeting

This year's AGM was held on February 9th at the Fairmont Palliser Hotel in Calgary. Major General Lewis MacKenzie put the "General" in this year's AGM making it the best attended in recent memory with 202 tickets sold. The executive, members and guest speaker were piped into the banquet hall by Reigh MacPherson. The AGM was conducted with little fuss and then dinner was eaten. After dessert and liqueurs, the General spoke to members/attendees about his experiences as a peacekeeper and specifically his activities in Sarajevo. His talk was both entertaining, thought provoking and informative. In appreciation, the CWLS presented General MacKenzie with a commemorative CWLS Blanket.

A new Honorary Member was inducted. Dave Greenwood has a long history with the CWLS. He was on the Executive in 1975 and 1976, and served as President in 1986. He was on the 1975, 1979 and 1983 Symposium Committees. Dave continues to contribute as the CWLS Parliamentarian.

Distinguished Service Awards were presented to Dave Curwen and Peter Kubica in recognition of their many years of service to the Society. This was Dave's second DSA. Dave has been involved with the society since the 70's. He has recently retired (at least from the log analysis business). Dave has written three papers (one in the 70's, one in the 80's, one in the 90's), served as U of C Liaison, served as APEGGA Liaison, was on convention committees and was on the Executive twice. Peter has served as Student Awards Chair for several years, served on the Executive, contributed to the Log Analysis Handbook, published a paper, chaired symposia technical sessions and presented luncheon talks. He is currently on the steering committee for the Kananaskis Topical Conference.

General Lewis MacKenzie and John Nieto. Photo courtesy of Jeff Levack.

Reigh MacPherson piping the members into the AGM as it opens.

Photo courtesy of Jeff Levack.

This year the CWLS also recognized a number of its volunteers. Each volunteer was presented with a commemorative CWLS blanket. The following people were recognized for their generous contribution of time and energy to the continuing success of the organization. Again the CWLS would like to thank each of these people for their hard work and dedication.

Executive (past and present members)
Jeff Levack, John Nieto, Robert Bercha, Mike Eddy, Richard Bishop, Khrista Kellett, Darren Aldridge, Dave Shorey, Dion Lobreau, Rosalie McDonell, Steve Burnie, Satwant Diocee

Speaker Evaluation Committee
Robert Bercha, Mirek Zoaral, Ken Watson, Larry Song, John Gilroy, Jim Earley, Mark Ducheck, Randy Hughes

Elections
Dave Reed

Contributions to the InSite
Ross Crain

Continued on page 21…

Annual General Meeting *… continued from page 20*

CWLS Convention Committee
Grant Spencer, Ken Faurschou, Doug Hardman, John Nieto, Mike Seifert

Web Site
Andrew Logan

Students Grant Committee
Peter Kubica

If your name appears above but you have not yet received your gift please contact John Nieto (President) or Jeff Levack (Past President)

Two other awards of note were given out. The President's Award for the best luncheon paper was presented to Robert Cluff. His paper was titled "Permeabilty Jail and Implications for Basin Centered Gas Production and Resource Assessment" and was presented at the April 14th, 2004 lunch. The talk provided a strong case for a contentious topic and introduced the concept of the 'permeability jail'. It was well received by the luncheon attendees. Mr. Cluff's presentation was very strong with solid graphics to support it.

The Vice-President's award was presented to Doug Hardman for his paper titled "Enhanced Petrophysical Interpretation Utilizing Digital Sonic Shear and Stoneley Wave Data". The paper was presented at the January 12, 2005 luncheon and provided the attendees with case studies, Canadian content and original material. The paper was well presented with high quality slides.

The new executive was introduced to the members and Jeff Levack handed the reigns over to John Nieto for the 2005 presidency. The 2005 executive looks very solid and we can expect great things from them this year.

Doug Hardman receiving the Vice-President's award from John Nieto for best Canadian Speaker from an E&P company.

Photo courtesy of Mike Eddy.

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.

An Investigation into Improved Permeability Prediction for the BKNE Field, Algeria, Using the Hydraulic Flow Unit Concept and Fuzzy Logic Analysis

Steve Winstanley – Senior Staff Petrophysicist, Anadarko Algeria Company
Uxbridge, London, February 2005

Introduction

The prediction of absolute permeability is a key element in reservoir descriptions and has a direct impact on, amongst others, effective completion designs, successful water injection programs and more efficient reservoir management.

Traditionally simple linear regressions of core porosity – permeability data or empirical formulae using various log responses (usually porosity, clay volume and water saturation) have been used to predict permeability. These empirical methods only apply locally and ignore the fact that there is no theoretical basis for a relationship between porosity and permeability. In addition the scatter of the data about the regression line is explicitly ignored and implicitly attributed to measurement error or lower order variability in reservoir characteristics.

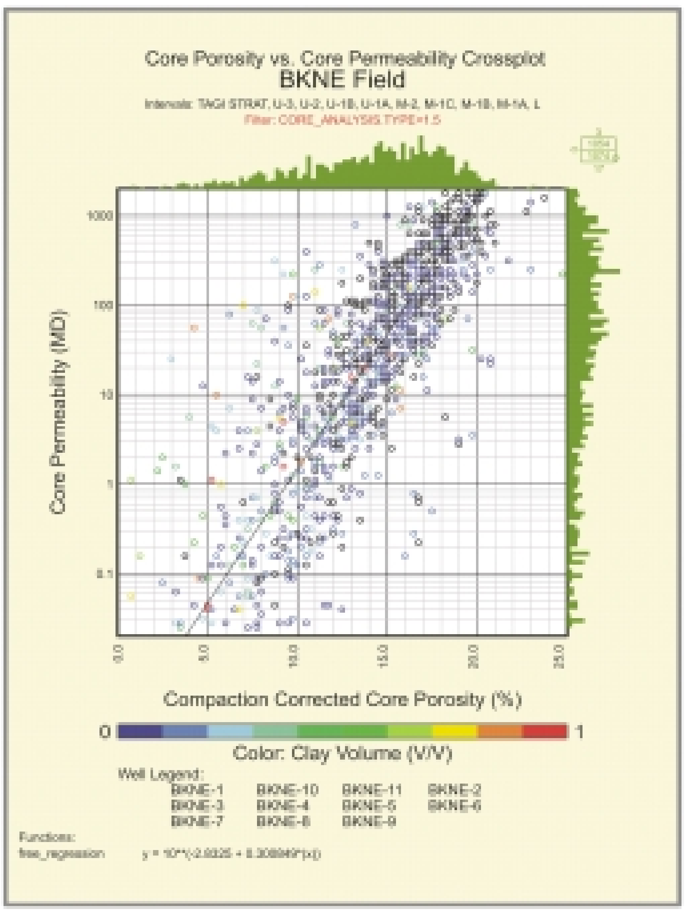


Figure 1. Core Porosity vs. Core Permeability Crossplot - TAGI Reservoir, BKNE Field

Permeability is predominantly controlled by pore throat size whilst porosity is predominantly controlled by pore size. As a result, for many reservoir sands deposited in complex depositional environments with inherited microscopic heterogeneity, a single porosity may give rise to a permeability that may vary by several orders of magnitude. This indicates the presence of several “hydraulic flow units” (HFU) of similar petrophysical characteristics. Analysis of core data from the Berkine North East (BKNE) Field in Algeria indicates such a scenario (Figure 1).

In their key paper Amaefule et al (1993), state that a “practical and theoretically correct methodology is proposed for identification of hydraulic units ..... based on a modified Kozeny-Carmen equation”. In doing so they make extensive use of core data to describe the complex variations in pore geometry and the identification of “flow zone indicators” (FZI) from hydraulic units, which are, in turn, implicitly linked to much improved permeability estimations.

Once FZI’s and HFU’s are identified from core data these need to be predicted in non-cored intervals or wells in order to estimate permeability. There are many predictive techniques available to the user. These include cluster analysis, multivariate analysis and neural networks. A further technique is fuzzy logic analysis. Fuzzy log analysis is a generalization of simple Boolean logic and has the benefit of being a powerful, easy to understand technique that is simple to use.

This brief article investigates the usefulness of the FZI and HFU concepts and the predictive capabilities of fuzzy logic analysis with a view to improving permeability estimates for the BKNE Field.

BKNE Field

The BKNE Field is located in Block 404 of the Berkine Basin, Algeria approximately 1000 km south-east of Algiers (Figure 2). The field was discovered in May 1996 by the BKNE-1 well and delineated in August 1998 by BKNE-2.

Continued on page 21…

Improved Permeability Prediction … *continued from page 20*

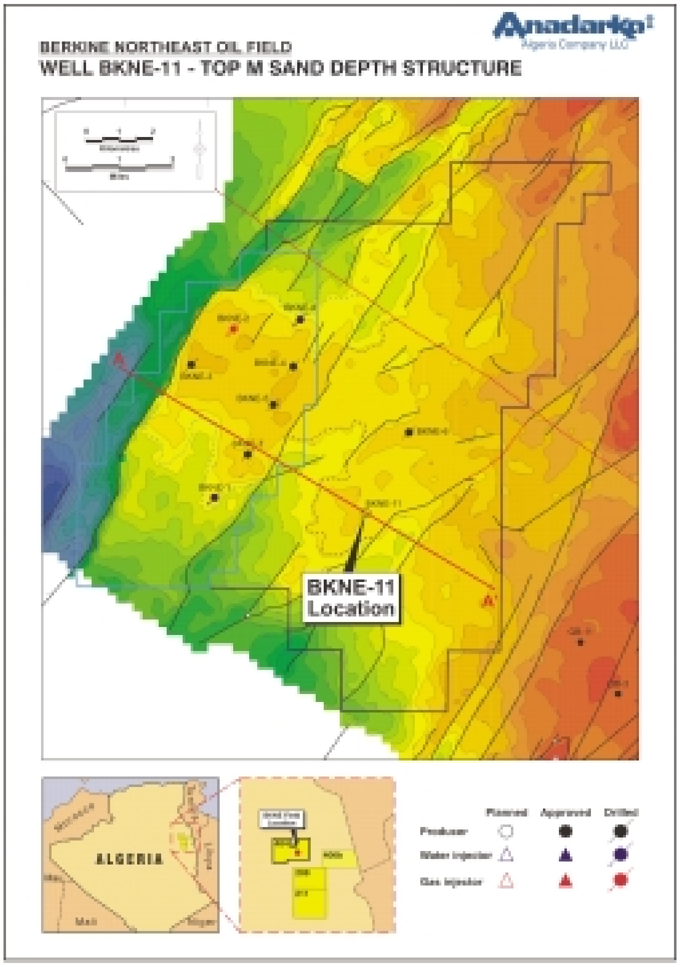


Figure 2. BKNE Field Location

These wells encountered between 25 and 45 metres gross TAGI interval and flowed oil to surface. Subsequent analysis of open hole wireline logs indicated some 10 to 20 metres of net reservoir with a mean effective porosity in the region of 14 to 18 % and air permeability between 50 and 200 mD. Some 5 metres of net pay thickness was identified in well BKNE-1 and 15 metres in well BKNE-2 with mean water saturation between 20 and 30 %.

Development drilling started in November 2001. A total of 11 wells have been drilled in the BKNE Field to date (Note: this article was first published in March 2003). The data from these wells showed the BKNE Field to be considerably more complex than originally thought with compartmentalization and differing oil types.

BKNE West

Seven wells have been drilled in the Western side of the field. The reservoir quality on this side of the field is generally very good, with kh's ranging from 1000 – 7000 mD-metres. The reservoir contains a volatile oil (GOR of approximately 3000scf/stb). The development plan for BKNE-West comprises crestal gas injection and peripheral water flood. Production started on 20 May 2002, with the field producing at a rate of 11,000stb/s oil.

BKNE Central

One well has been drilled in the Central part of the field. The reservoir quality on this side of the field is moderate, with a kh of 3000 mD-metres. As with BKNE West, the reservoir contains a volatile oil (GOR of approximately 3000scf/stb). Work is in progress to determine the optimum development plan.

BKNE East

Three wells have been drilled in the Eastern side of the field. The reservoir quality here is moderate, with kh's ranging from 1000 – 3700 mD-metres. Unlike the BKNE West and Central areas, BKNE East contains a black oil (GOR of approximately 475scf/stb). Further delineation to the north & south will take place later in 2003. Work to determine the optimum development plan for BKNE-East has not been finalised, with work in progress.

TAGI Reservoir

The BKNE Field TAGI reservoir was deposited in a (mainly) terrestrial fluvial environment, producing laterally continuous sand bodies normally capped by claystone beds representing flooding episodes. The full range of depositional environments include palaeosol, chott (lacustrine) margin, chott basin, deltaic, fluvial and aeolian.

The TAGI reservoir is a predominantly quartz rich sandstone with shale and claystone interbeds. Sandstone is predominantly composed of quartz and K-feldspar with traces of (but very locally abundant) siderite, pyrite, mica, glauconite and dolomite. Clay is predominantly illitic (argillaceous rock fragments) although locally kaolinite and chlorite are important. The reservoir sands range from fine (silty) to lower medium grain size. The clays range from pure to shaly. The clay/shalestones are predominantly laminated in nature.

Continued on page 22…

Improved Permeability Prediction *… continued from page 21*

The reservoir is split into three geological units – the Upper (U), Middle (M) and Lower (L). These are further sub-divided into 10 units based on a combination of electro-facies and depositional facies derived from preliminary core descriptions.

Figure 3 shows how the TAGI reservoir character manifests itself on a neutron – density crossplot. Plotting all data from the BKNE Field, the figure exhibits a classic "L" shape. This is indicative of water/oil filled predominantly fluvial deposited sands. Matrix supported sand (A) degrades in grain size to silt sized particles which, in combination with clay sized particles, produce mud-supported shalestones (B). As clay content increases pure wet claystones are observed (C).

Figure 1 shows the core porosity – permeability relationship for the TAGI reservoir. It shows that for a field average, net reservoir porosity of around 16.0% permeability ranges between 20 and 400mD.

Available Data

The TAGI reservoir has been logged with a comprehensive logging suite (Table 1). With the exception of BKNE-2 (Western Atlas), all logs were acquired by Schlumberger.

Table 1. BKNE Field – Typical Logging Suite

Tool	Logs
AIT-DSI-PEX-CNL-GR	Array induction resistivity Compression and shear transit time Bulk density, Photo-electric effect Neutron, Gamma ray, Caliper
NGT-UBI-GR	Spectral / Compensated gamma ray Thorium, Potassium, Uranium Ratios

The log data has undergone a thorough processing program to generate properly quality controlled, edited, depth matched, merged and borehole corrected logs.

In addition, all wells have, to a greater or lesser degree, been cored. Conventional core analysis, including grain density, porosity and air permeability measurements, have been undertaken for all of the BKNE wells by The Centre de Recherche et Development (CRD) in Hassi Messaoud. Core plugs from the first two wells, BKNE-1 and BKNE-2 were also sent to Reservoir Inc in Houston (now Corelab) for conventional core analysis.

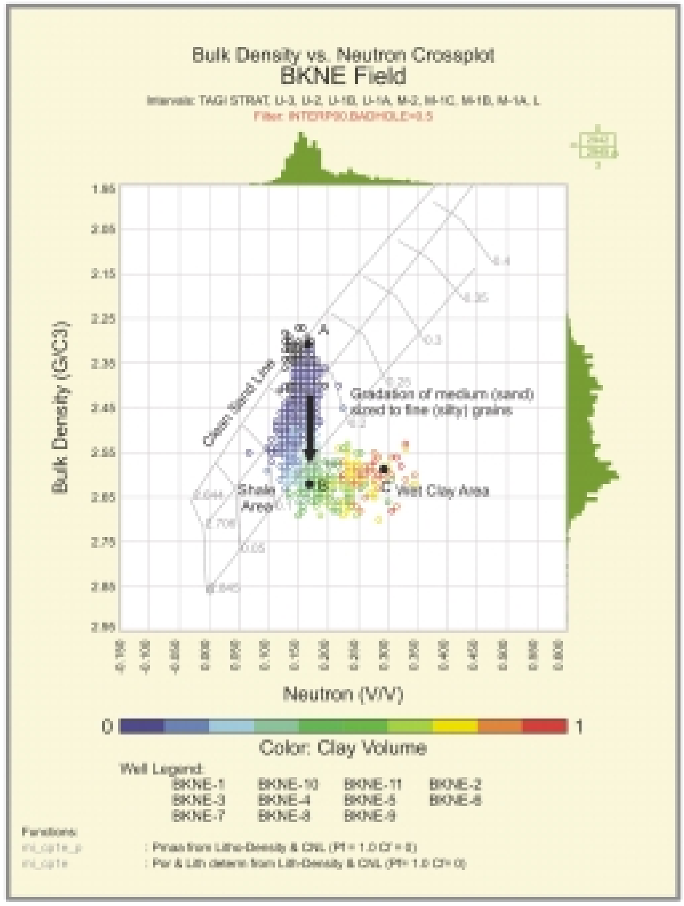


Figure 3. Neutron vs. Density Crossplot - TAGI Reservoir, BKNE Field

Core porosity measurements have been corrected for the affects of net overburden pressure. A very limited data set suggests that the difference in air and klinkenberg corrected permeability is negligible. To date, no data has been acquired to determine the impact of net overburden pressure on permeability. Therefore the permeability data used in the reservoir characterization is as reported by the laboratory.

The core analyses from the various laboratories are of comparable quality. However careful scrutiny of the data is a pre-requisite of it's use in any analytical application. As such the core data set is heavily filtered to remove non-valid or suspect core

Continued on page 23…

Improved Permeability Prediction ... *continued from page 22*

samples due to fracturing, breaking or improper cleaning. The filtered data set is used in the subsequent analyses and discussions presented here.

Petrophysical Analysis

Static Reservoir Properties

A deterministic sand-silt-clay model has been employed to calculate reservoir petrophysical properties. Judicious selection of petrophysical parameters and methodology compensates for any influence of the minor exotic minerals described above.

Clay volume has been calculated from the minimum of the Product Index (Potassium * Thorium), neutron-density and density-sonic cross-plot methods. The minimum value reduces the over-estimation of all clay volume methods in the absence of gas and bad hole effects. Where bad hole is present the crossplot methods have not been used. The selection of matrix, fluid and clay parameters used in the various methods have been determined from an inspection of core and log frequency histograms and neutron-density-sonic crossplots. Analysis of the crossplots and effective porosity calculations have allowed the determination of the nature of the clay distribution in the reservoir sands, i.e. structural (VCLSTRUC), dispersed (VCLDISP and laminated (VCLLAM).

Silt volume (VSILT) has been calculated from the difference of the clay volume and the shale volume (VSHDN). Shale volume has been calculated from the neutron-density crossplot method as described above with the exception of selecting a shale point rather than a wet clay point (see Figure 3).

Total porosity (PHITD) has been calculated from the density log. The density log has been calibrated to available compaction corrected core porosity (CPORCCF) on a well, zone and fluid leg basis. The calibration is fixed at 0% porosity to median core grain density (determined on a well and zone basis) and regressed to 100% porosity to determine the apparent fluid density. Where core is not present representative values, as determined on a field wide basis, have been used.

Total porosity has been corrected for the presence of clay to determine effective porosity (PHIED). Wet clay density values have been selected on a well and zone basis. The correction for clay is minimal.

Where bad hole has been identified the Wyllie time average sonic porosity method has been used. The petrophysical parameters used in this method have been determined in a similar manner to the density porosity.

Total (SWTI) and effective (SWEI) water saturation has been calculated using the Indonesia equation. TAGI formation water is super-saline. This equates to a formation water resistivity (R_w) in the region of 0.015 ohm-m at a reservoir temperature. R_w is corrected at every level for the reservoir temperature. True formation resistivity (R_t) has been taken from the deepest reading of the Array Induction resistivity device. Archie (a), cementation (m) and saturation (n) parameters of 1.0, 2.0 and 2.0 respectively have been used. These are based on regional analysis of special core analysis on cores from Block 404 wells. Clay resistivity has been selected from an inspection of frequency histograms of R_t across 100% claystone beds. A typical clay resistivity is in the order of 1 to 2 ohm-m.

The static reservoir characterization is considered to be accurate and robust. Good agreement between the clay indicators is readily achieved and matches the limited XRD clay content measurements from core analysis quite well. However, it is possible that the clay content maybe slightly under-estimated. Further XRD analysis is currently being carried out to improve the clay volume calculations.

Overall there is a very good agreement between calculated total porosity and compaction corrected core porosity. The same can also be said of the comparison between log water saturation and Dean-Stark core water saturation in the irreducible water leg.

"Lithology" Log Responses

A wide variety of other interpreted log responses can be calculated from the input logs and the basic reservoir property logs. Most of these are described in the literature as being indicative of the reservoir lithology since the manipulation of the input logs extracts the affects of porosity. However experience has shown that these logs still retain information pertaining to sand reservoir texture and reflect differences in depositional and diagenetic control on the rock types encountered. These are described in Appendix A.

Dynamic Reservoir Properties

To date log air permeability has been predicted using either multivariate techniques or straight forward porosity-air permeability regressions depending on the geological zone, fluid leg and core data availability. Multivariate techniques have been deemed necessary due to the large range of air permeability for any one porosity as observed from core analysis. The log permeability equation is given by :-

Continued on page 24...

Improved Permeability Prediction … continued from page 23

MVPERM =
$10^{(x+a*BVW+b*PHIED+c*SWEI+d*VCLMIN+e*TNPHCC+f*RHOCC+g*VSHDN+h*CKALF+j*CPORCCF)}$

Where,

MVPERM = Air permeability (mD)
BVW = Bulk volume of water (PHIED * SWEI) (v/v)
PHIED = Effective porosity (v/v)
SWEI = Effective water saturation (v/v)
VCLMIN = Clay volume (v/v)
TNPHCC = Neutron log (v/v limestone)
RHOCC = (Bulk density (g/cc)
VSHDN = Shale volume (v/v)
CKALF = Core air permeability (mD)
CPORCCF = Compaction corrected core porosity (%)

The match between core and predicted log porosity is, in the main, only reasonable. At very low and very high core permeabilities the predicted permeability is not considered to be a good match . This is due in part to the techniques used and the vertical resolution of the input logs not being able to match the heterogeneity of the reservoir rock permeability as described by core analysis. As such permeability-thickness and arithmetic or geometric mean permeability calculations may have significant error.

Hydraulic Flow Units and Flow Zone Indicators

A hydraulic flow unit (HFU) is defined as the representative volume of total reservoir rock within which geological properties that control fluid flow are internally consistent and predictably different from properties of other rocks. The hydraulic quality of a rock is function of pore geometry that is, in turn, controlled by the rock mineralogy and texture. Various combinations of these controlling factors can lead to distinct rock flow units with similar hydraulic properties. Therefore hydraulic units do not necessarily coincide with geological or depositional facies boundaries.

"Determination of pore throat attributes is central to accurate zoning of the reservoir into units of similar hydraulic properties" (Amaefule, et al). If a porous medium is considered as a bundle of straight tubes then a combination of Darcy's Law for flow in porous media and Poiseuille's Law for flow in tubes can be combined for rock permeability:-

$$k=\left(\frac{r^2}{8}\right)\phi e$$

Where,

k = Permeability (μm²)
ϕ = Effective porosity (v/v)
r = Tube radius (μm)

The relationship clearly shows that the factor relating permeability to porosity depends on the pore characteristic. Kozeny-Carmen adapted this simple relationship to a realistic model for porous media where pore tubes are neither straight nor uniform in radius by adding a tortuosity factor and using the concept of mean pore radius. The mean pore radius is defined as the ratio of cross sectional area to the wetted perimeter. The generalized Kozeny-Carmen equation is given by:-

$$k=\left(\frac{\phi e^3}{(1-\phi e)^2}\right)*\left(\frac{1}{Fs\tau^2 * Sgv^2}\right)$$

Where,

$Fs\tau^2$ = Kozeny constant (ranges between 5 to 100) where Fs is the shape factor (2 for a perfect cylinder)

Sgv^2 = Surface area per unit grain volume

In reality the Kozeny constant is only constant within given hydraulic units but is variable between units. Manipulation of the equation and using permeability in conventional millidarcy units removes this problem to give:-

$$0.0314*\sqrt{\left(\frac{k}{\phi e}\right)}=\left(\frac{\phi e}{(1-\phi e)}\right)*\left(\frac{1}{Fs\tau * Sgv}\right) \quad (1)$$

The three main elements to this equation can be described as follows:-

$$0.0314*\sqrt{\left(\frac{k}{\phi e}\right)}=$$

RQI = Reservoir Quality Index (μm)

$$\left(\frac{\phi e}{(1-\phi e)}\right)=$$

ϕz = Pore volume to grain volume ratio

Continued on page 25…

Improved Permeability Prediction … *continued from page 24*

$$\left(\frac{1}{Fs\tau * Sgv}\right) =$$

FZI = Flow Zone Indicator (μm)

Further re-arrangement of the above gives:-

log RQI = log ϕz + log FZI

Therefore on a log-log plot of RQI versus ϕz all samples with similar FZI values will lie on a straight line with units slope. The value of the FZI constant is determined by the intercept of the line with ϕz = 1. Samples that lie on the same line have similar pore throat attributes and therefore constitute a hydraulic unit.

Figure 4 shows the RQI versus ϕz crossplot for the BKNE Field data set. FZI is plotted on the z-axis. If we consider FZI values of between 10 and 12μm – colored dark orange/red on the z-axis – the data points fall on a straight line (A). The same can be said of other FZI bands.

The above theory suggests that there should be one FZI value per HFU. In practice however there is a distribution for each FZI around its' mean due to random measurement error in core analysis. In addition if there are multiple HFU's their associated FZI distributions are superimposed. As a result there will be a continuum of FZI values on the RQI versus ϕz crossplot. This is the case with the BKNE data set as shown in Figure 4.

Equation (1) above can be further developed to give:-

$$k = 1014 * (FZI)^{2*} \left(\frac{\phi e^3}{(1-\phi e)^2}\right) \qquad (2)$$

This equation is represented in Figure 5 for the BKNE Field data. This plot is the same as Figure 1 with the z-axis colour coded for FZI. The plot clearly shows how much permeability estimates can be improved with the integration of FZI and porosity. If we consider a field average net reservoir porosity of

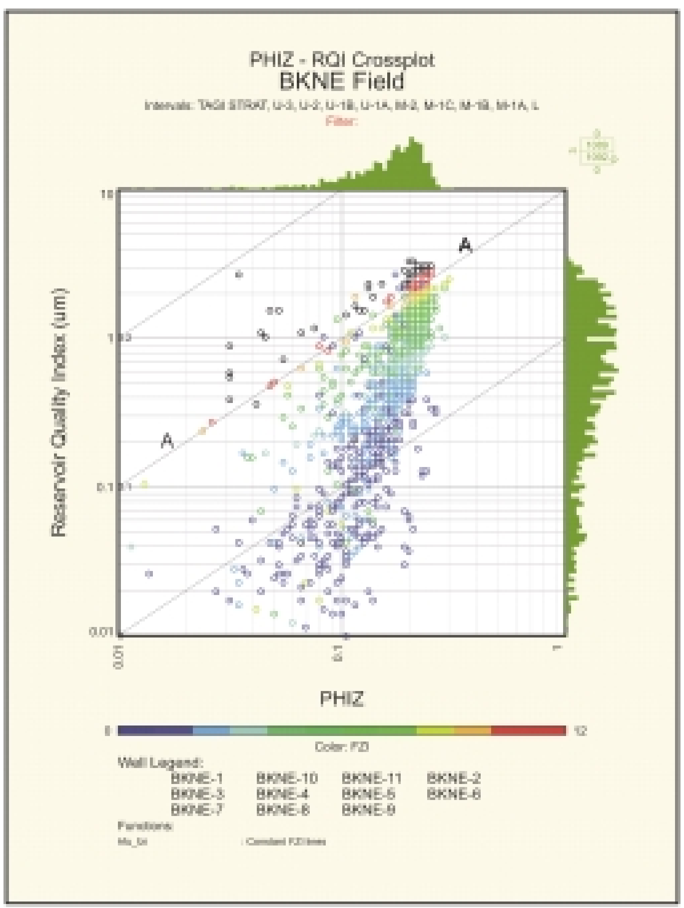


Figure 4. PHIZ vs Crossplot – TAGI Reservoir, BKNE Field

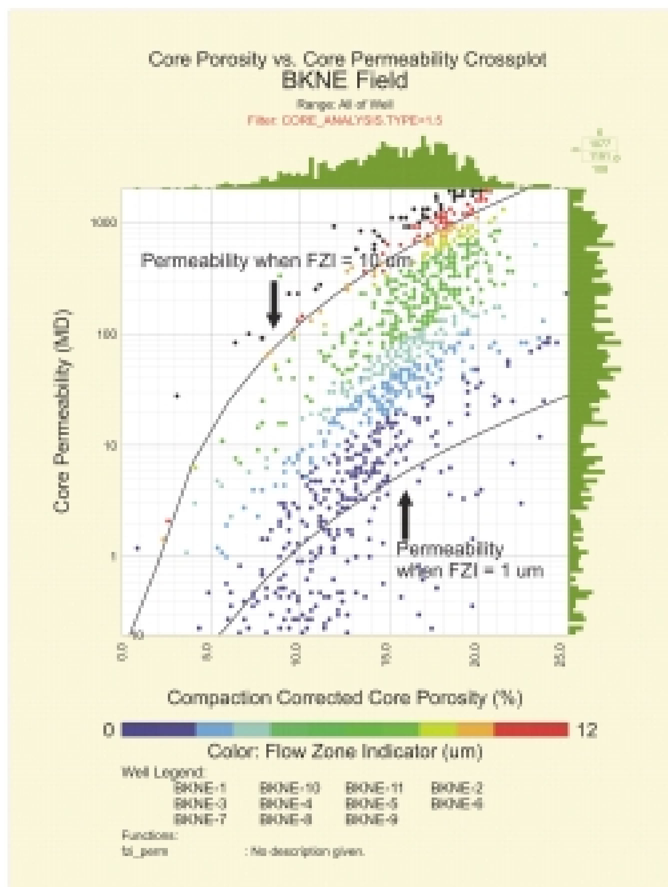


Figure 5. Core Porosity vs Core Permeability – TAGI Reservoir, BKNE Field

Continued on page 26…

Improved Permeability Prediction … *continued from page 25*

16% the traditional porosity-permeability transform would give a predicted permeability range of anywhere between 10 and 1200mD. If we are able to consider a particular HFU or FZI, for instance FZI of around 11(m, then our predicted permeability range is reduced to between 700 and 1000mD – a vast improvement.

The objective now is to predict HFU or FZI in non-cored intervals.

HFU and FZI Prediction From Fuzzy Logic Analysis

The above discussion has been based on the analysis of core data. HFU and FZI need to be predicted away from cored intervals for the methodology to be of any real use. There are many predictive techniques available to the geoscientist. These include cluster analysis, multivariate analysis and neural networks. A further technique is fuzzy logic analysis.

Fuzzy logic analysis is a generalization of simple Boolean logic and has the benefit of being a powerful, easy to understand technique that is simple to use.

Boolean Logic

Boolean logic assigns classification based on discriminating criteria whose boundaries are sharply defined. It is assumed that all the change in classes occurs at class boundaries and that little change of importance occurs within classes. However, such a rigid model ignores important aspects of reality which are, in our case as follows:-

- Distribution of FZI values about the mean value for any HFU
- Variation in lithology, texture and sorting
- Tool response inaccuracy
- Lack of tool precision
- Imprecise definition of HFU/FZI classification
- Inaccurate classification discriminators

Diagram #1 shows an example of this. We could try to define facies 1, 2 and 3 based on certain clay volume cut offs. However, it is clear from the clay volume distribution that there will be errors or uncertainty in the predicted facies. For example, facies 1 will be predicted (where clay volume is less than 0.4 v/v) for a number of intervals where in reality facies 2 is described.

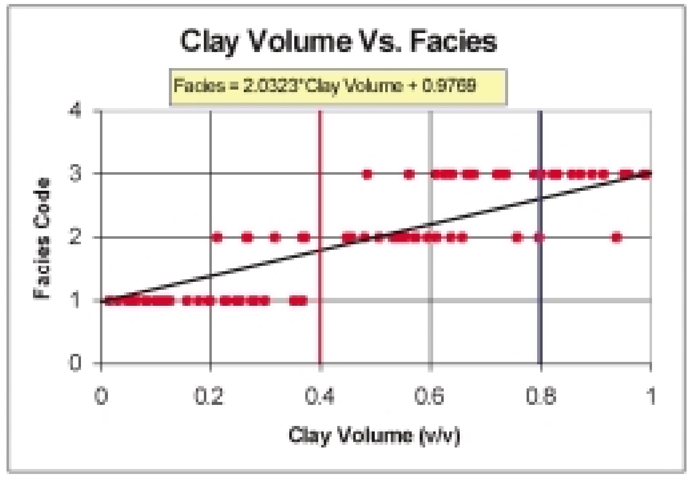


Diagram 1.

Fuzzy Logic

Fuzzy logic is a generalization of Boolean logic whereby classification is based on a gradual transition. Fuzzy logic is designed to handle inexactness in a definable way and can lead to quantitative analysis of joint membership of any class.

Diagram #2 shows the same data as above but plotted as a normalized frequency histogram. This shows how each of the three facies overlap each when clay volume is used as a discriminator. Fuzzy logic analysis interrogates these distributions for any number of discriminators. For any given discriminator the possibility of classification membership can be calculated. For example if clay volume is 0.3 v/v there is a 0.70 possibility of facies 1 membership and a 0.18 possibility of facies 2 membership.

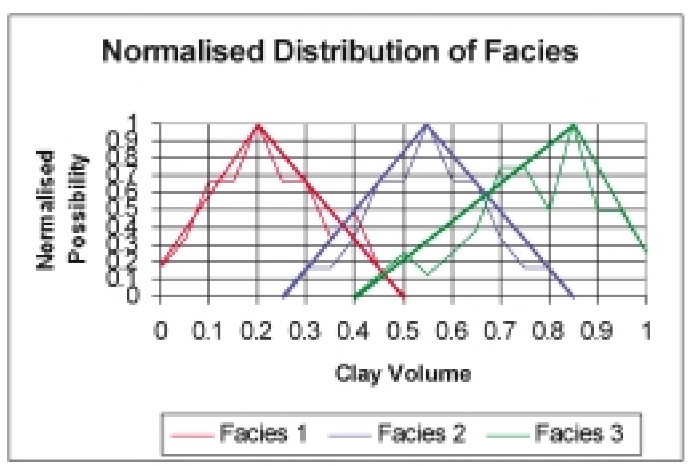


Diagram 2.

Continued on page 27…

Improved Permeability Prediction … *continued from page 26*

Depending on the number of classes it is possible to have membership of more than 2 classes. In this case clay volume values of between 0.40 and 0.50 could indicate membership of all 3 classes. However, the most likely case is for membership of facies 2.

Given the above, fuzzy logic analysis needs as a pre-requisite:-

- Good quality class membership description (i.e. the number and value of HFU's we wish to predict for)
- Good quality predictors (i.e. fully QC'd openhole log data and accurate and consistent petrophysical results)

Class Membership

As described above from Figure 5, the BKNE Field apparently exhibits a large number of HFU's which manifest themselves as a continuum of FZI values.

The number of HFU's we wish to predict is crucial to the overall objective of improved permeability estimation from equation (2). If we select too few HFU's then the permeability prediction will have too wide a range. If we select too many we may not be able to predict the class membership accurately enough from logs. This study has taken a pragmatic approach during this preliminary investigation.

Figure 6 shows a frequency histogram of FZI for the BKNE Field. The histogram shows that there are 5 relatively distinct groupings of FZI distributions. A further "group" exists where FZI has a value of greater than 10.7 (m. These are the main HFU's for the this reservoir.

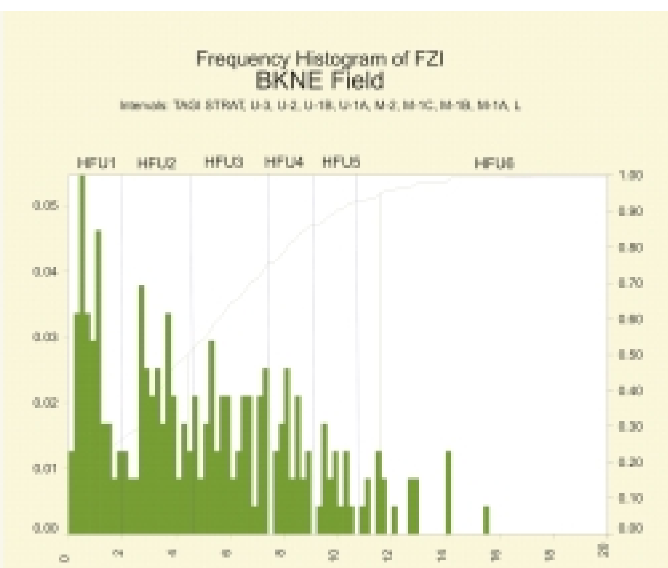


Figure 6. FZI Frequency Histogram - TAGI Reservoir, BKNE Field

Table 3 shows which calculated HFU's have been identified using FZI boundaries from the above histogram and the arithmetic mean FZI values have been assigned for each HFU.

Table 3. BKNE Field – Hydraulic Flow Units and Associated Arithmetic Mean Flow Zone Indicator

HFU	FZI Lower	FZI Upper	Mean FZI (μm)
1	0.0	2.0	0.8
2	2.0	4.5	3.3
3	4.5	7.5	5.5
4	7.5	9.0	8.2
5	9.0	10.7	9.7
6	10.7		13.9

Log Predictors

If we are confident in the above classifications the primary consideration when embarking on fuzzy logic analysis is choosing which discriminators/predictors best describe the variations in HFU.

Spearman's rank correlation has been used to calculate the degree of correlation between the HFU values and a variety of open hole and interpreted logs. The best 6 correlations are shown in Table 4.

Table 4. BKNE Field – HFU Spearman Rank Correlation

Tool	All TAGI	Rank
MN	0.436	5
NLITH	0.446	4
PHITA	0.495	1
RHOCC	0.494	2
SWEI	0.456	3
VSILT	0.412	6

The table shows that from the available data set there is a statistically valid correlation between HFU and the identified open hole and interpreted logs. The table only shows 6 of the 24 correlated logs since this is the maximum number of predictors allowed in the software. Of the 24 only 4 did not have a statistically valid correlation.

Continued on page 28…

Improved Permeability Prediction *... continued from page 27*

These results are gratifying in that, intuitively, these logs reflect the four main controls on permeability – porosity, water saturation, clay/silt volume and texture.

HFU Prediction and Permeability Calculation

The fuzzy logic module in the GEOLOG software package has been used to predict HFU. The prediction has two phases:-

1. The 6 logs are calibrated to HFU by finding the fuzzy correlations. For each HFU, a probability distribution is built such that a particular log reading will be most probable but any reading is finitely possible.
2. On a depth by depth basis, the individual curve values are evaluated using the above correlations to provide a fuzzy possibility that a particular HFU is the most likely answer.

In this preliminary investigation the data set used in phase 1 included all the wells except BKNE-1, BKNE-3 and BKNE-11. Data from BKNE-1 and BKNE-11 have been excluded on the grounds that core analysis is not considered to be a true representation of the reservoir properties due to inadequate cleaning of the core plugs. Well BKNE-3 has been excluded to provide a "blind-test" data set.

Having determined HFU and assigned its' arithmetic mean FZI from Table 4 permeability is simply calculated using equation (2) and log effective porosity.

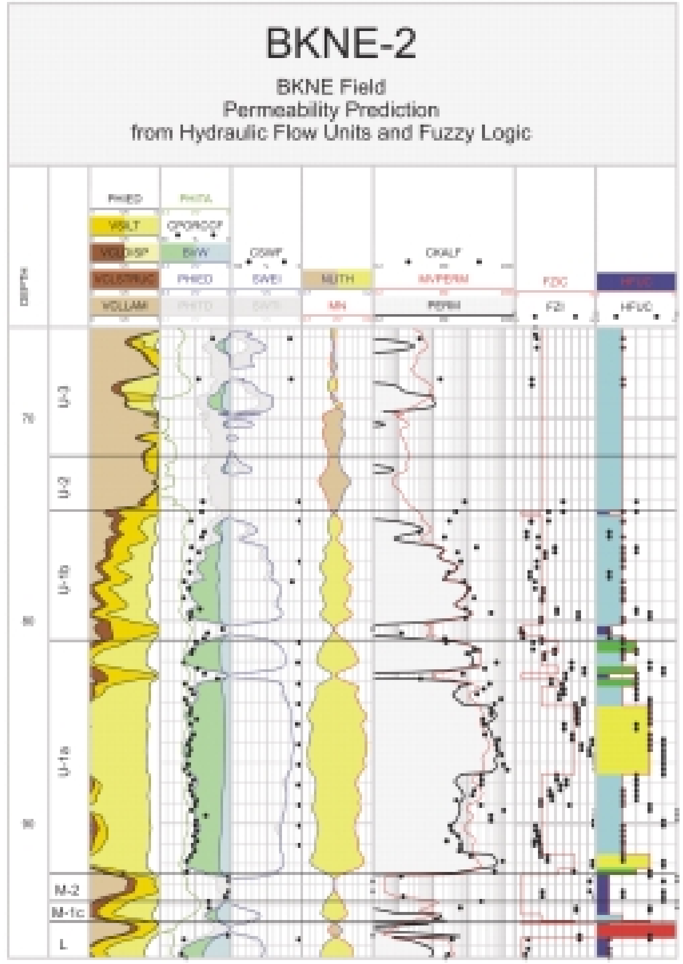


Figure 7.

Results

Figures 7 to 15 are CPI plots showing the result of the petrophysical analysis and the fuzzy logic prediction of HFU and the resultant permeability.

Track 3 shows the lithological composition of the TAGI reservoir.

Track 4 shows log effective and total porosity (PHIED and PHITD) and compaction corrected core porosity (CPORCCF). The track also plots apparent total porosity (PHITA) used in the fuzzy logic analysis.

Track 5 shows total and effective water saturation (SWEI and SWTI) and Dean-Stark water saturation (CSWF).

Track 6 shows the lithology indictors N (NLITH) and MN used in the fuzzy logic analysis.

Track 7 shows permeability from both the HFU interpretation (PERM) and log prediction methods (MVPERM) together with core air permeability (CKALF).

Track 8 shows the FZI values calculated from core analysis (FZI) and the FZI values assigned after the determination of HFU from fuzzy logic analysis (FZIC).

Track 9 shows the HFU's determined from the "binning" of the core analysis FZI data and the HFU's predicted from fuzzy logic analysis.

The CPI plots show that in the majority of the wells the prediction of HFU is good. Wells BKNE-2, 6, 7 in particular, and most of wells BKNE-9 and 10, show a good comparison to core derived HFU. The quality of the prediction is further illustrated by a comparison of the core derived FZI and the FZI assigned by predicted HFU.

The prediction of HFU is poorer in wells BKNE-4, 5 and 8. BKNE-5 is an interesting example. Well BKNE-5 has very similar log derived petrophysical properties to BKNE-7. The

Continued on page 29...

Improved Permeability Prediction *… continued from page 28*

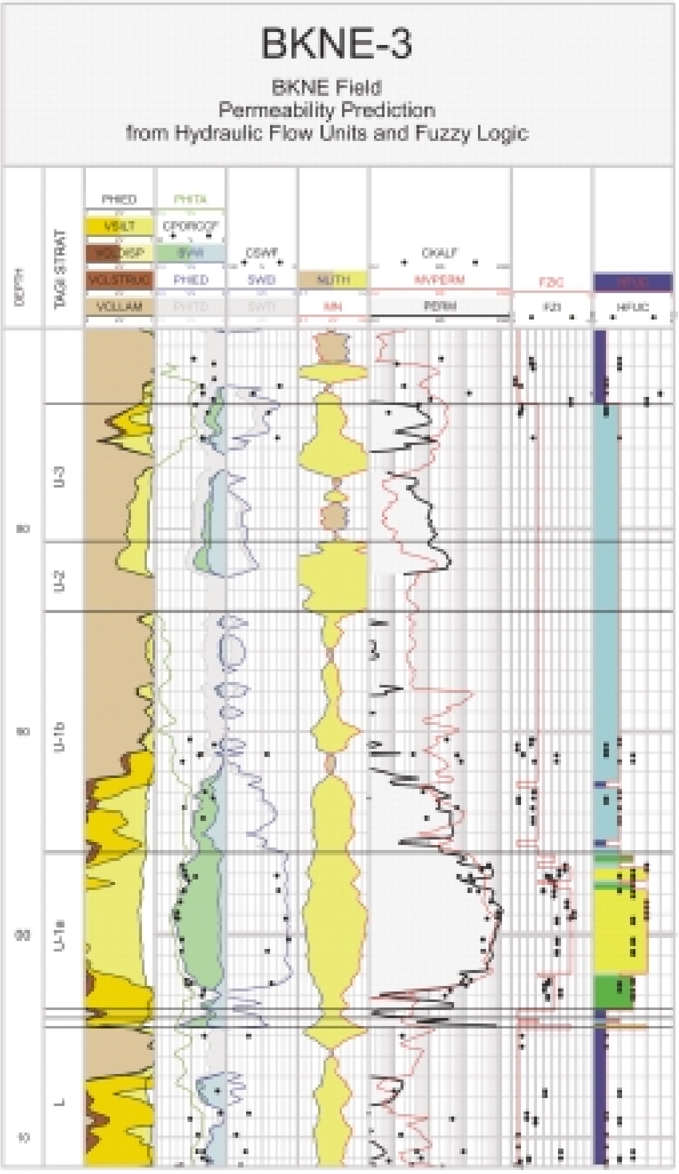


Figure 8.

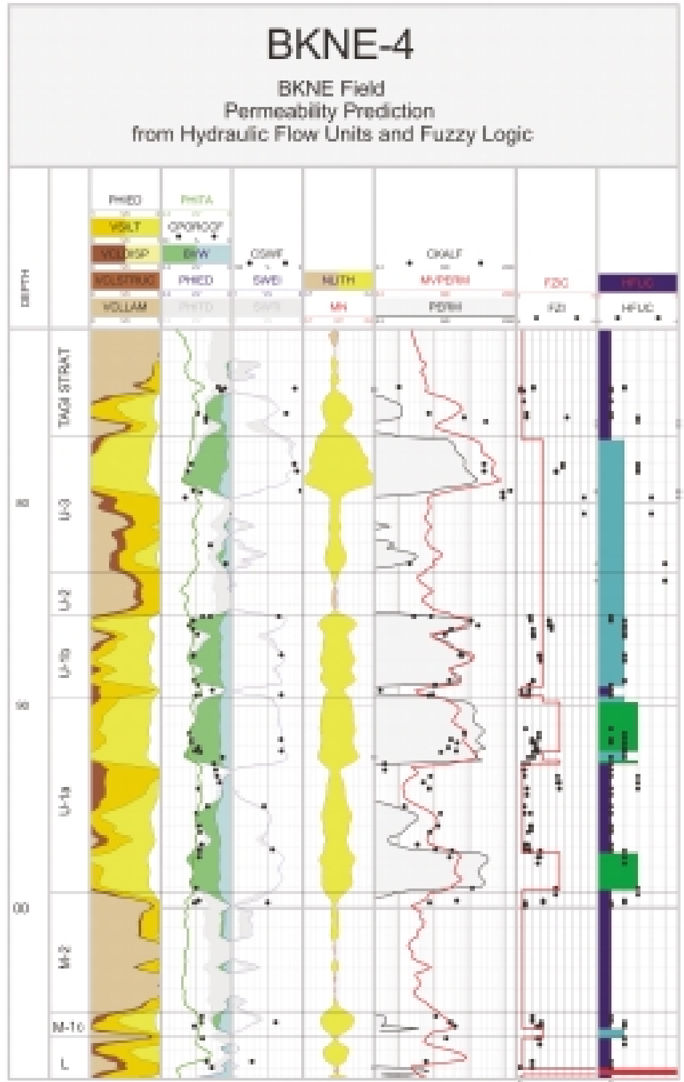


Figure 9.

quality of the fuzzy logic results, however are poorer in BKNE-5 than they are in BKNE-7. In BKNE-5 the overall variation in predicted FZI follows the trends shown by the core derived FZI. However, in detail, the core derived FZI shows much more variability. This suggests that the apparent reservoir heterogeneity in BKNE-5 may be due to a problem with the core analysis results.

A further test of this technique is the comparison of core permeability and predicted permeability. In nearly all cases the HFU derived permeability is superior to the existing multivariate and simple porosity- permeability regression methods. Two particular strengths of the new technique are improved prediction at the extremes of the permeability range and more realistic vertical variability or heterogeneity. Examples include:-

- BKNE-7 shows a much better permeability prediction in the M-1c zone where an increase from around 600mD to 2000mD is observed.
- BKNE-2 shows a better permeability prediction in the U-1a zone, between XX84 and XX87.5 mrkb, where an increase from around 2000mD to 600mD is observed.
- BKNE-9 shows an increase in predicted permeability variability compared to the simple porosity- permeability regression method in the M-1c zone. In particular the predicted

Continued on page 30…

Improved Permeability Prediction *… continued from page 29*

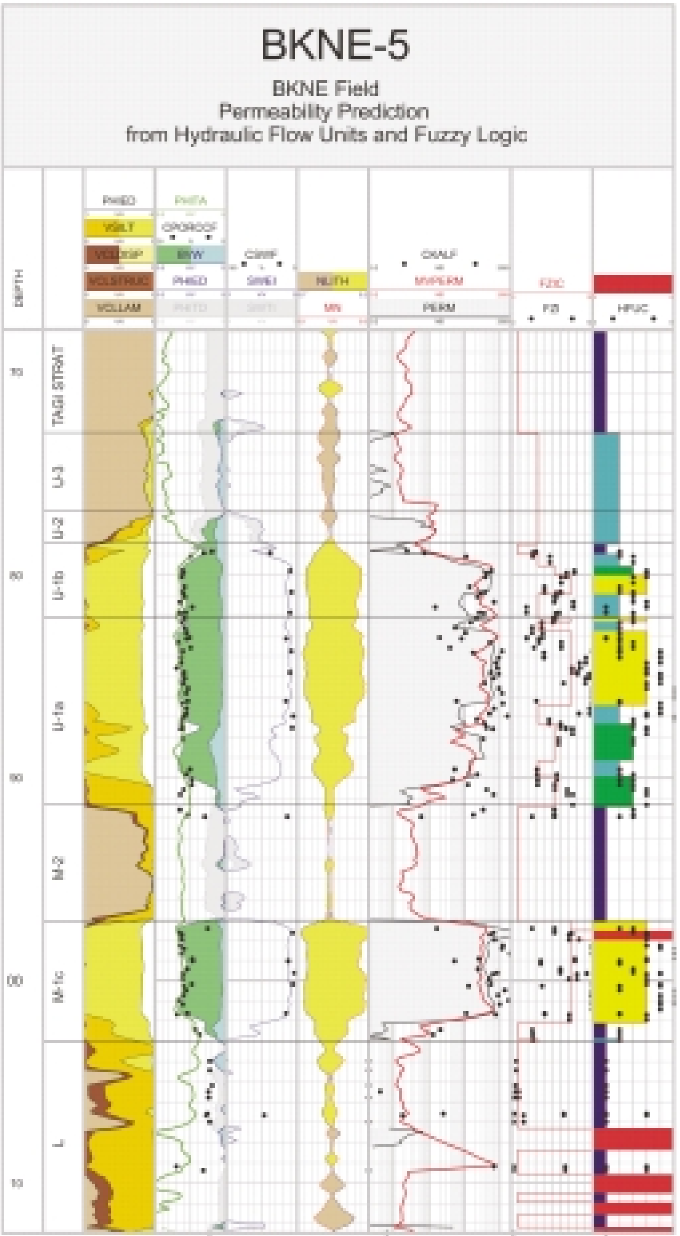


Figure 10.

permeability in the poorer quality sands between XX99 and XX04 mrkb are better defined.

- BKNE-6 shows an increase in predicted permeability variability compared to the simple porosity- permeability regression method in the M-1c zone.

The final test for the validity of this technique is the results of the "blind-test" well BKNE-3. The results are very good. There is an excellent match to core derived HFU, FZI and air permeability. Of particular note are the more realistic permeability

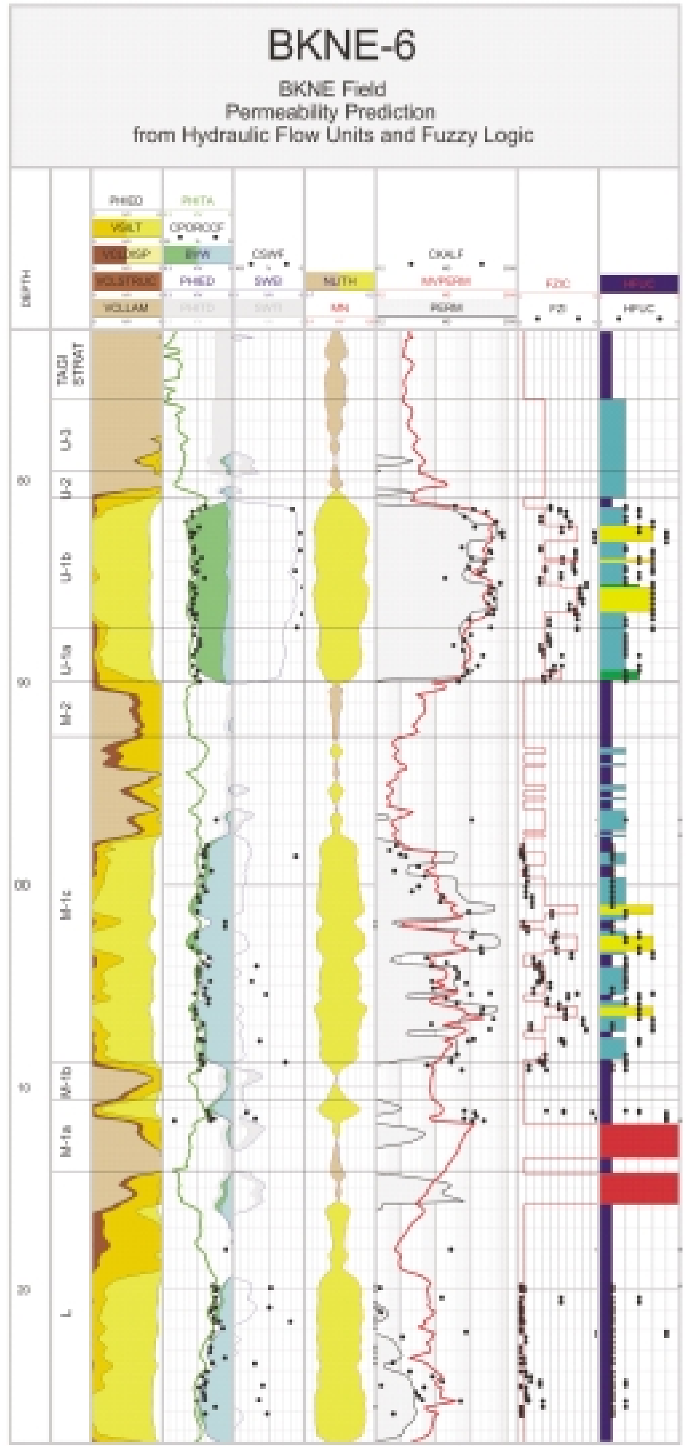


Figure 11.

Continued on page 31…

Improved Permeability Prediction *... continued from page 30*

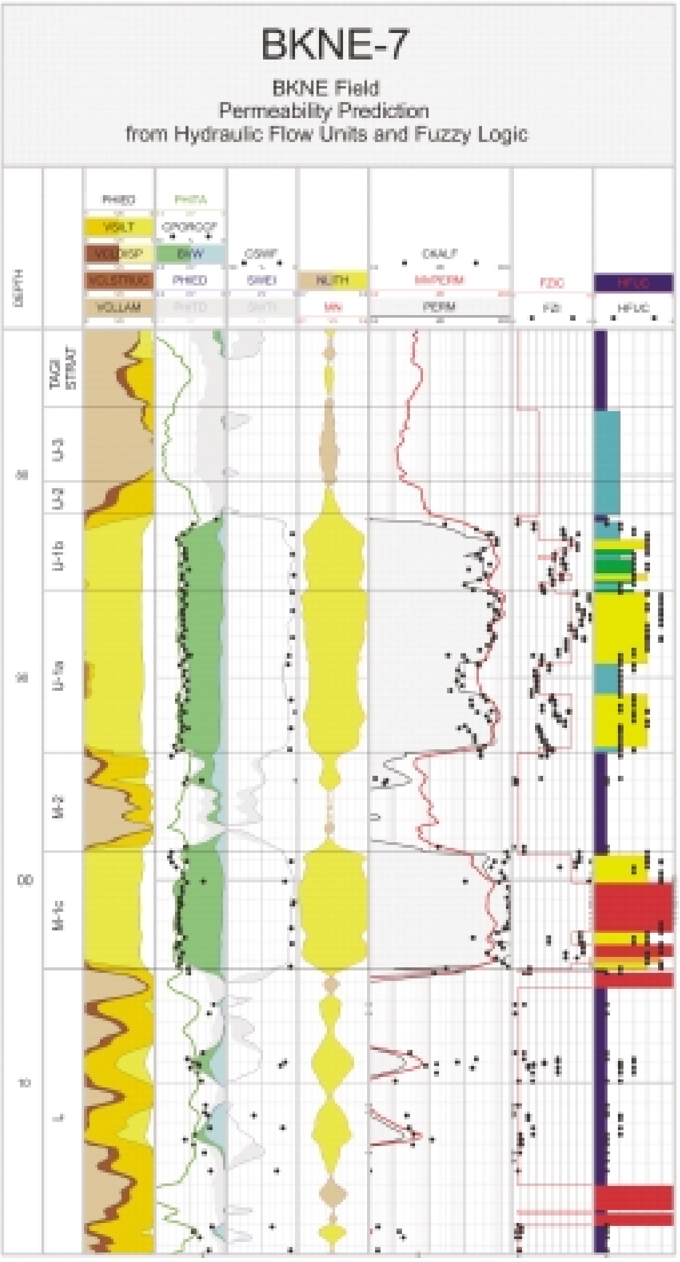


Figure 12.

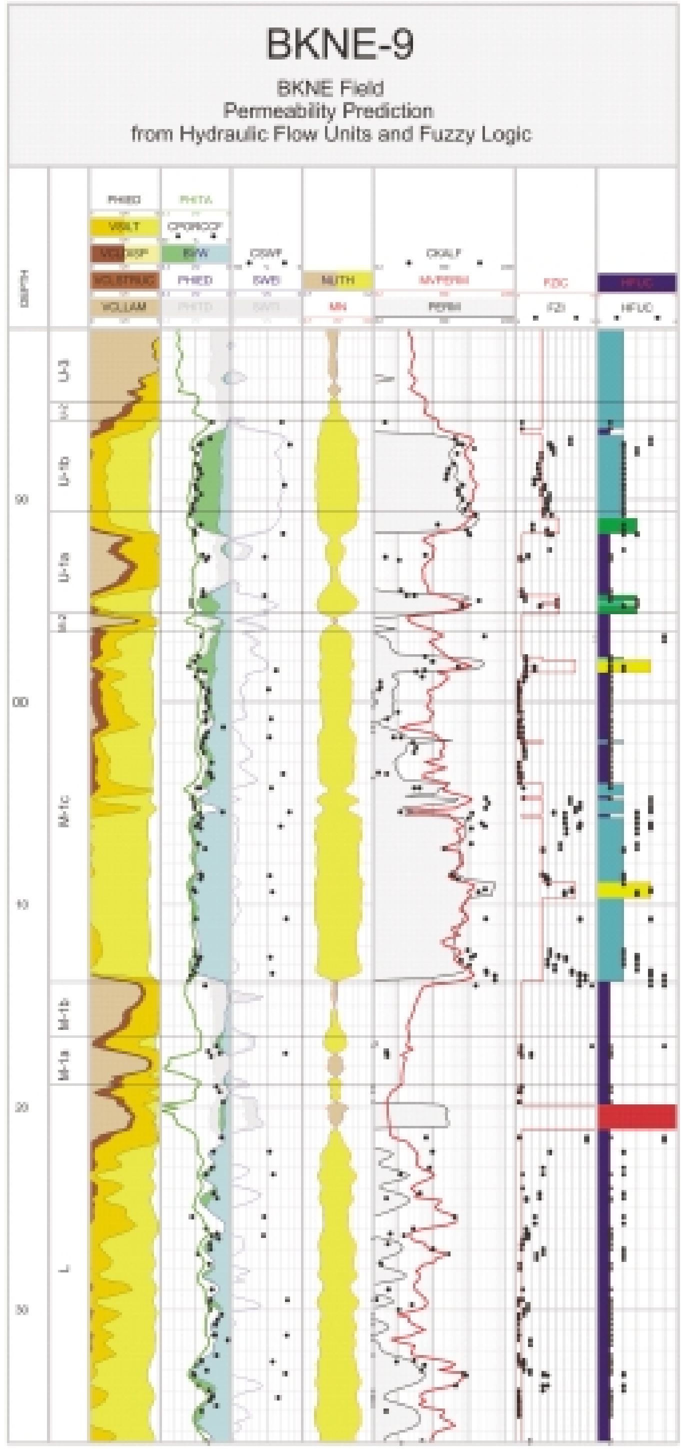


Figure 13.

profiles in the U-2 and U-1b intervals and the improved permeability in the marginal net reservoir sands of U-3.

Conclusions

The preliminary investigations of the BKNE data set in order to detect hydraulic flow units and flow indicators and their impact on improved permeability prediction appear to validate the concepts proposed by Amaefule.

Continued on page 32...

Improved Permeability Prediction … *continued from page 31*

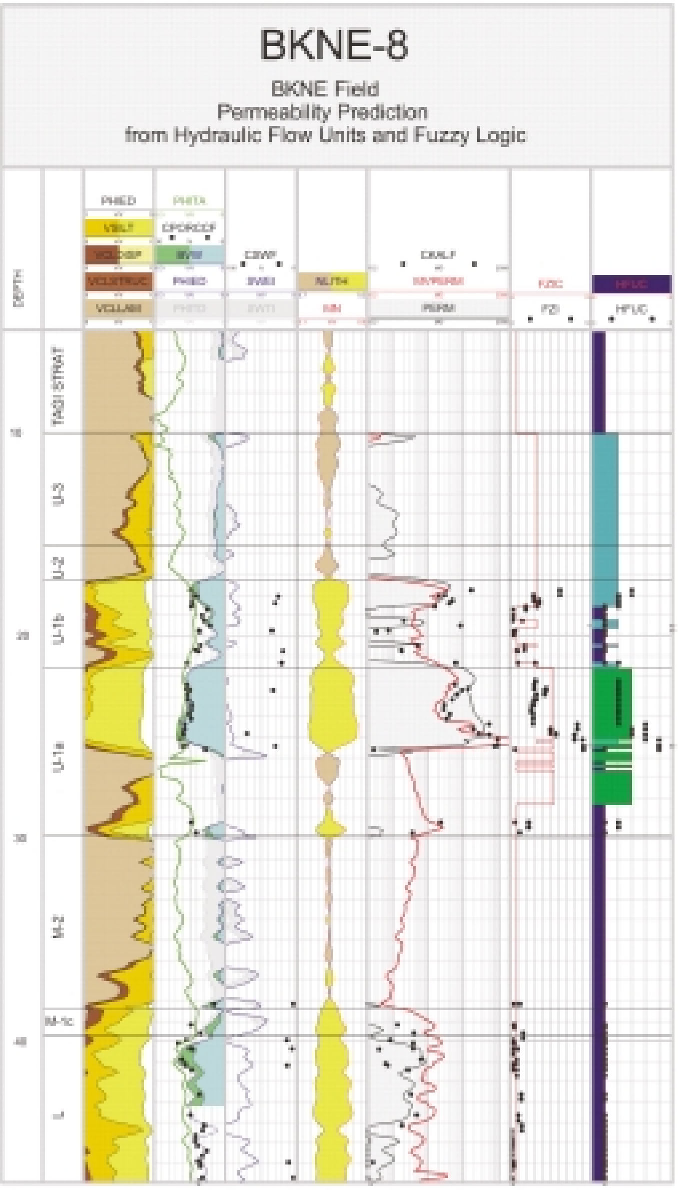


Figure 14.

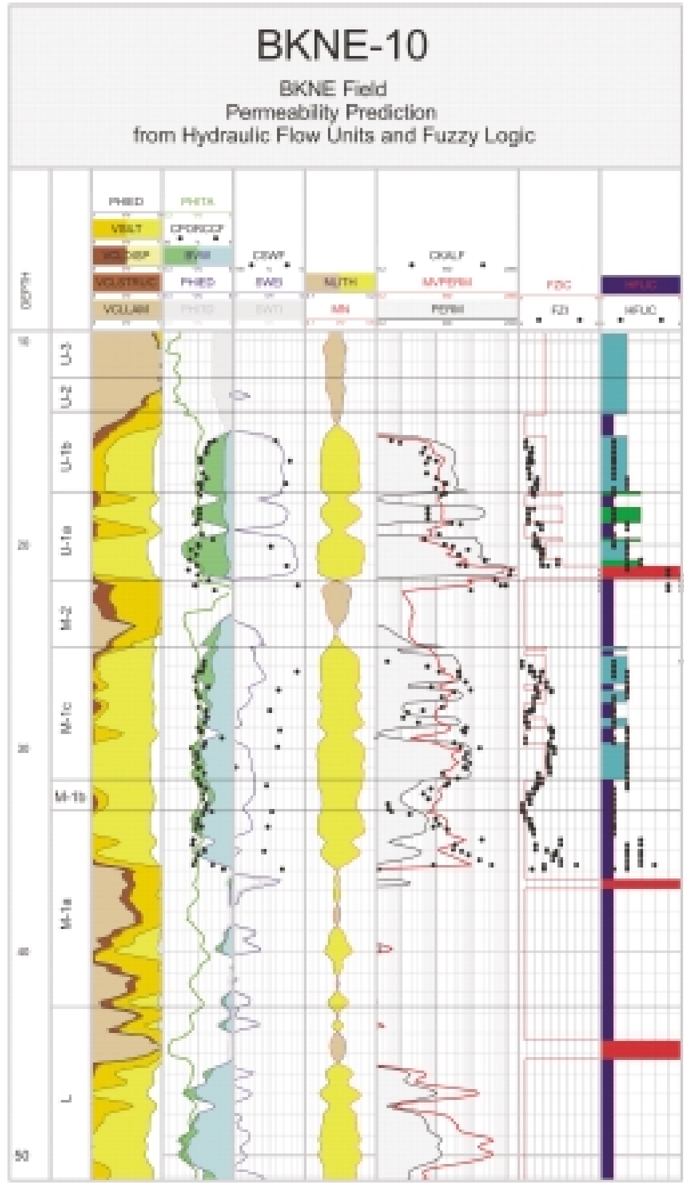


Figure 15.

At least 6 HFU's can be clearly identified from the data. These HFU's can be successfully predicted using the fuzzy log analysis method. In turn predicted permeability from FZI shows an improvement over existing permeability prediction techniques. As a result permeability can be better predicted in non-cored intervals or wells.

It is clear that the improvement in permeability prediction will, in addition, increase the accuracy of water saturation – height functions using RQI, lead to better understanding of permeability barriers or baffles thereby improving reservoir simulation models and lead to better well completion designs.

Despite the apparent success of this investigation it is important to understand that fuzzy logic analysis is a tool and not a solution. Experience shows that an iterative approach to HFU class membership (both number and associated FZI values) and the integration of logs improves results. The above results indicate that whilst improvements in permeability prediction have been made there are occasions where the method has not

Continued on page 33…

Improved Permeability Prediction ... *continued from page 32*

been successful. Additional work in the following area needs to be carried out in order to improve further the permeability predictions:-

- A review of the quality of the core analysis results
- The identification of the optimum number of HFU's
- An investigation into the prediction of FZI instead of HFU
- A confirmation of the consistency of the open hole petrophysical analysis
- An investigation into the impact of using different data sets for the fuzzy logic "learning" phase, i.e. by individual fluid legs, geological zones and net / non-net intervals
- The use of more relevant core permeability measurements, i.e. oil permeability at irreducible water saturations, compaction corrected permeability

Acknowledgements

The author would like to thank the following fellow Groupement Berkine Block 404 Satellites team members for their contribution and help in writing this article – Dave Wheller, Anthony Cole, Berkani Hassene, Boulam Ikhlef, El-Hafed Habhouba, Elizabeth Loudon, Sandra Fountain and Imad Ahriche.

About the Author

Stephen Winstanley is currently a Senior Staff Petrophysicist with Anadarko Algeria Company, London. He graduated from the Victoria University of Manchester in 1985 and worked with a number of leading consultancies in the U.K. before joining AAC in 1998. He was seconded to Groupement Berkine (A Sonatrach / Anadarko joint venture) in 1999 and spent the next four years working in the Algerian Sahara providing petrophysical support and guidance to operational issues and the development of reservoir models for some ten fields. He returned to the U.K. in early 2004 and is currently involved in the first equity determination of two Algerian fields.

References

Amaefule, J.O., Attunbay, M., Tiab, D., Kersey, D.G. and Keelan, D.K.: "Enhanced Reservoir Description: Using Core and Log Data to Identify Hydraulic (Flow) Units and Predict Permeability in Uncored Intervals/Wells", SPE 26436

Cuddy, S.J.: "Litho-facies and Permeability Prediction from Electrical Logs using Fuzzy Logic", SPE 65411 (49470)

Appendix A

"Lithology" Log Responses

$$Mlith = \left(\frac{(Dtf - DT)}{(\rho b - \rho f)}\right) * 0.01$$

$$Nlith = \left(\frac{(\phi Nf - \phi N)}{(\rho b - \rho f)}\right)$$

$$MNlith = Mlith * Nlith$$

$$Plith = \frac{Nlith}{Mlith}$$

$$DtMAA = Neutron / Sonic - chart$$

$$\rho MAA = Neutron / Density - chart$$

$$\phi TAA = Neutron / Density - chart$$

Where,

Dtf = Fluid transit time ($\mu s/ft$)

Dt = Transit time ($\mu s/ft$)

ρb = Bulk density (g/cc)

ρf = Fluid density (g/cc)
ϕNf = Neutron fluid ($l.p.u.\ v/v$)
ϕN = Neutron ($l.p.u.\ v/v$)

$DtMAA$ = Apparent matrix transit time – including shale ($\mu s/ft$)

ρMAA = Apparent matrix density – including shale (g/cc)
ϕTAA = Apparent total porosity – including shale (v/v)

A Note on Professional Registration for Engineering Graduates in the Logging Business

The following is an excerpt from the APEGGA publication: *Experience Requirements for Licensure – An Experience Guideline for Members-in-Training, Examination Candidates, Students and Applicants*.

…it will be to your advantage if your experience is not exclusively in any one of the following areas:

- sales administration or management
- feasibility or economic studies
- geoscience field studies/operations
- supervision of production
- computer programming or systems analysis
- geological sample description
- supervision or inspection of construction
- maintenance planning
- drafting
- startup or commissioning of plant
- construction estimating
- well-site geology
- patent examination and filing
- technology school teaching
- postgraduate studies in other fields
- military service
- well logging
- cadastral and construction surveying
- stratigraphic section measurement
- geophysical processing

If your experience is in one of the preceding areas, the amount of credit you receive may be less than the actual time spent in that position if the work does not contain significant application of engineering or geoscience principles or if the work is not being performed at a high enough level.

At the request of the CWLS, APEGGA has agreed to remove well logging from the list of occupations that are suspected of not providing adequate experience for professional registration. Over the next few months, references such as the one above will begin to disappear from the APEGGA literature. Of course, any applicants for registration are still required to show a suitable level and range of experience.

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.

Canadian Well Logging Society

Wednesday, April 13, 2005

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

Time:	**12:00 pm (Cocktails at 11:30 am)**
Reservations By:	**Friday, April 8, 2005, (noon) – Call 269-9366 to Confirm a Seat**
Cost:	**Members reserved meal (with confirmed seat): $25.00; Members at the door: $30.00** **Non-Members reserved meal: $30.00; Non-Members at the door: $30.00** **(Special needs meals available with advanced booking only)**
Topic:	**The Application of Novel Formation Evaluation Techniques to Complex Tight Gas Reservoirs**
Speaker:	**Steve Cuddy, Helix RDS**

Abstract:

As the larger hydrocarbon accumulations on the UK Continental Shelf become depleted, geoscientists are challenged to develop new techniques to produce from complex smaller discoveries. This paper describes the development and application of novel formation evaluation techniques to enable production from complex gas reservoirs.

The example used in this paper involved a large structure, which had long been recognized but was not developed due to a variety of technical challenges including the thin-bedded nature of the sediments and the presence of both mobile and immobile viscous residual oil. The oil is a highly viscous liquid, which if produced, could block production tubing due to the shallow depth of the reservoir and associated low pressures. To successfully produce dry gas, identification of both oil and gas zones was necessary to enable gas zones to be perforated, and oil zones to be excluded.

During the development drilling campaign the reservoir was appraised by using a formation evaluation program specifically designed to address the presence of oil within the thinly bedded reservoir. In conjunction with core data and high resolution electric logs, nuclear magnetic resonance tools were used to identify and avoid perforating zones with higher oil saturations.

Over the reservoir interval, there were significant intervals of borehole washout. Badly affected logs were repaired using fuzzy logic. This technique finds relationships between electrical logs in order to create synthetic logs, which are used for quality control, to infill data gaps and to repair sections of poor log.

In order to understand the variation in reservoir quality and to correlate between wells, litho-facies and permeability were predicted throughout all wells. Genetic algorithm and fuzzy logic techniques were used to find relationships between the electrical logs and the core results. These relationships were used to predict continuous litho-facies and permeability curves together with a visual and numerical comparison of their uncertainty.

Formation fluid types were derived from the nuclear magnetic resonance measurement (NMR). A pattern recognition technique that analyses the entire shape of the T1 and T2 distributions was used to derive the volumes of gas, oil and water. The technique was calibrated using Dean and Stark fluid analysis data and the results were used to ensure that the perforation strategy avoided oil bearing sands.

This paper describes the subsurface challenges and how, through the application of novel formation evaluation techniques, a complex tight gas field has been characterised.

Biography:

Steve Cuddy is the Principal Petrophysicist with Helix-RDS. He is an Honorary Research Fellow with Aberdeen University and is director with Petro-Innovations Ltd. Previously he spent 10 years with Schlumberger and 15 years with BP. He holds a doctorate in petrophysics and his principle interest is the application of soft computing techniques and Sw-height functions to formation evaluation.

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

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

CWLS GENERAL INFORMATION

INCORPORATED – January 21, 1957

Objective

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

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

(B) Encouraging research and study with respect thereto.

MEMBERSHIP

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

FEES

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

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

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

ACTIVITIES

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

Research committees encourage and support research on relevant problems.

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

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

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

APPLICATION

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

CWLS MEMBERSHIP APPLICATION FORM

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

NAME:..

COMPANY:..

COMPANY
ADDRESS:...

....

HOME
ADDRESS:...

....

E-MAIL ADDRESS:...

PREFERRED MAILING ADDRESS:

E-MAIL____ OFFICE____ HOME____

BUSINESS
PHONE:..

RESIDENCE
PHONE:..

PROFESSIONAL
DISCIPLINE:..

....

SIGNATURE:..

DATE:... , 20 ....

CWLS SPONSORS: (Members in good standing)

Name: ....

Phone:..

Name: ....

Phone:..

FEES

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

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

Tech Corner: Coalbed Methane; an Unconventional Reservoir with Challenging Petrophysical Needs

Background

The Coalbed Methane (CBM) business in Canada began in earnest in 2000. The Pan Canadian – MGV partnership and their Horseshoe Canyon exploration brought an exciting new dimension to the conventional oil and gas exploration in the Western Canadian Sedimentary Basin. Unlike previous CBM exploration and drilling, this initiative proved to be the beginnings of the first commercial production from this unconventional resource in the basin.

From the first few wells in 2000, activity is growing dramatically with PSAC forecasting two to three thousand CBM wells for 2005.

This explosion of drilling and production brings with it new challenges for the petrophysical community, including our CWLS members. Typical lithology, porosity and water saturation techniques we are familiar with in conventional reservoirs have little application in coals. Alternate methodologies using wireline logs and core must be considered.

Further restricting the knowledge growth is the extreme confidentially surrounding CBM, where operators share little if any information. However, with near-record gas prices, the business is forging ahead and we must meet these new challenges.

With well production similar to shallow gas wells (3.4 e^3m^3/Day or 120,000 mscf/day), economics play an important role. Maximizing financial returns from CBM production requires optimizing the production rates and gas recovery, while keeping development and operational costs low. A key component of this process is optimizing production well design through: well placement, reservoir evaluation, completion, stimulation and production. Selecting and implementing project development strategies requires knowledge about important subsurface characteristics of target CBM reservoirs including:

- Location and distribution of available coal gas reserves,
- Gas content of coal resource,
- Permeability and producibility of these reserves,
- Net coal thickness,
- Reservoir pressure,
- Mechanical characteristics of the coals and surrounding beds that influence stimulation,
- Characteristics of surrounding beds that influence production including:
  - propensity for water production from adjacent aquifers
  - co-mingled hydrocarbon production from adjacent reservoirs
- Initial water disposal options for wet coals.

Well evaluation is the primary means of obtaining this information. In particular, wireline logs provide rapid, continuous, in-situ subsurface measurements of key properties relating to CBM resources, providing valuable input to project development decisions.

Accepting well production is low, cost-effective wireline logging options are key to project economics in the production phase. However, since CBM production can be quite variable laterally and vertically in prospective horizons, understanding the important reservoir parameters early can prevent significant surprises later. The released data from the Black Warrior in Alabama (Figure 1) illustrates the extreme production variability often exhibited by coal gas reservoirs. This twenty-six well, wet coal study illustrate, the individual well cumulative production differences exceeded 2265 E3M3 or 80,000 Mscf after two years of production.

We might ask why these variations occur and will we too be faced with this dramatic production range here in Western Canada? Although not formally published, local results discussed publicly by various operators, suggest we are indeed facing this situation.

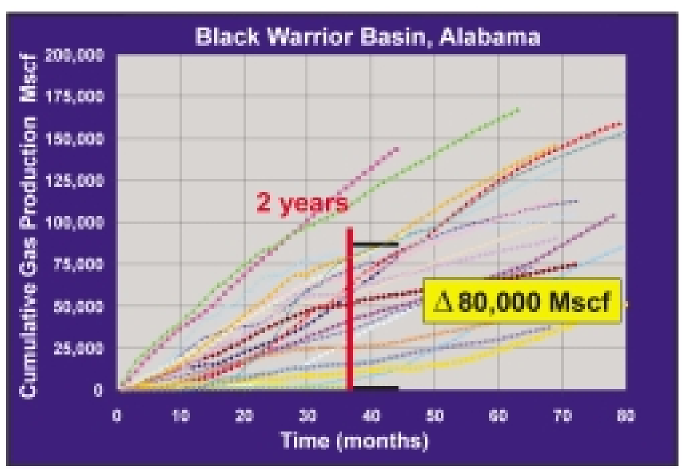


Figure 1. Black Warrior Basin cumulative production variations.

Continued on page 38…

Tech Corner … *continued from page 37*

To help answer gas in place (GIP), rate prediction and other questions, numerous measurement options are available to meet the evaluation goals at different stages of field development. As field-specific experience and knowledge levels improve, evaluation needs typically change. Exploration and pilot well logging suites are normally more extensive than production wells. As well, control wells with more extensive suites are often used to confirm reservoir understanding as further drilling and completions occur. Area wide coal-to-log relationships established or confirmed early in project life through more comprehensive logging suites lead to simplified, lower cost evaluation solutions in the production phase. These measurement options vary by providing different types and amount of information, different levels of dependability and field calibration reliance. In the production phase, it is expected most evaluation will occur in cased hole with open hole control wells as required.

Traditional logs, such as high resolution density, integrated with innovative analysis algorithms are used to develop local GIP models based on core and production data. Existing density-dependent algorithms may or may not apply in all applications and typically require fine-tuning and/or additional, supplemental measurement(s). Petrophysicists are very familiar with the dependence of a correct density porosity on matrix density. Similarly, coal evaluation requires a specific knowledge of the ash density (i.e. the non-coal material remaining after the coal is burned in the presence of air until the sample weight stops changing). The presence of carbonates (e.g. calcite), sulfides (e.g. pyrite) or other heavy minerals can have a significant impact of GIP calculations developed from density relationships without these materials, similar to traditional petrophysical evaluations.

Exploration, Pilot and Control Well Evaluation

Resource Evaluation: Nuclear-Core Integration

Early in project life, more extensive evaluation is normally needed to better define the CBM resource. Advanced coalbed evaluation suites may require a geochemical log. Geochemical logs measure specific elements including silicon (Si), calcium (Ca), iron (Fe), sulphur (S), titanium (Ti) and gadolinium (Gd). Combination of these elements allows quantification of common reservoir minerals, including quartz, carbonates, clays, pyrite, siderite and anhydrite. Presence and variations of these minerals has a significant impact on coal composition and lithology determination, impacting the resulting gas content computation. With processing and analysis tailored to the specific needs of CBM evaluation, including the geochemical log provides more robust, reliable, and comprehensive evaluation answers. Reliance on expensive and time-consuming core for field/zone specific coal properties can be significantly reduced.

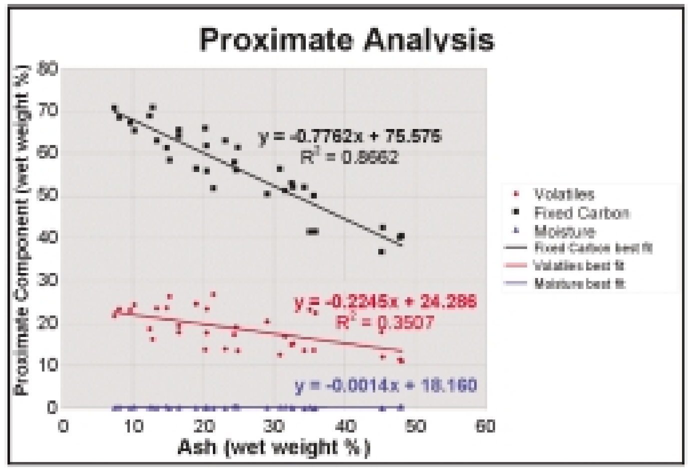


Figure 2. Core Proximate Analysis, relating ash content to moisture, volatiles and fixed carbon.

A typical process for combining core proximate analysis with log data is described:

- **Estimate Total Ash Content**
  - From core proximate analysis (discrete results at sample plug depths only), Figure 2 illustrates a typical result for a series of samples in a specific coal.

  And/or

  - From conventional density and spectroscopy services (continuous, in-situ).
- **Derive Constituents (Moisture, Fixed Carbon, Volatiles)**
  - From core proximate analysis, create locally developed empirical relationships for moisture, volatiles and fixed carbon as a function of ash as noted in Figure 2.

  Or

  - From density, PE, neutron and spectroscopy (ideally, calibrated with core analysis). Spectroscopy only plays a key role when the coal or ash properties are changing. However, this variation can be common.

Continued on page 39…

Tech Corner *… continued from page 38*

- **Determine Coal Rank**
  - $\text{Rank} = \dfrac{\text{Fixed Carbon}}{\text{Fixed Carbon} + \text{Volatiles}}$
- **Estimate potential coal gas content**
  - Using rank, pore pressure and temperature in an appropriate desorption/adsorption isotherm model developed through laboratory testing of crushed, coal core samples.
  - Common isotherm models include Langmuir and Kim's equation.
  - Figure 3 illustrates a Langmuir isotherm family, relating pore pressure, coal rank and gas content for a given reservoir temperature. For specific coal sample testing, the rank is constant, resulting in a single isotherm.
  - Incorporate the proximate analysis, isotherm and reservoir pressure into the interpretation model to calculate gas in place by bed and cumulatively.
- **Qualitatively Determine Coal Cleating**
  - Using ash mineralogy from density and spectroscopy services.
  - Using microelectrical imaging tool interpretation of mega cleats presence, density and direction.

The principle of spectrometry-based cleat presence and significance is based on a number of assumptions that may or may not apply to all coals:

- Mineral deposition from water having flowed through the cleat system gives an indication of the presence of cleating,
- Clay and sand inhibit cleating if present in large amounts,
- Secondary mineralization (calcite, pyrite) indicative of well-developed cleating if not too extensive.

Given the importance that cleating plays in producibility, this technique is worth consideration.

Figure 4 shows an advanced well log interpretation, integrating resistivity, neutron, density, gamma ray and spectrometry logs with core proximate and isotherm data. Note, the good agreement between the core and log derived gas contents. The coal is partly cleated by response definition.

Pressures and Permeability: Wireline Testing

Coal insitu pressure is critical to evaluating methane adsorbed in the coal. The laboratory determined isotherm is a reflection of the maximum amount of gas that can adsorb onto the coal. An accurate measurement of the coal reservoir pressure in conjunction with the isotherm describes the actual gas adsorbed and saturation condition.

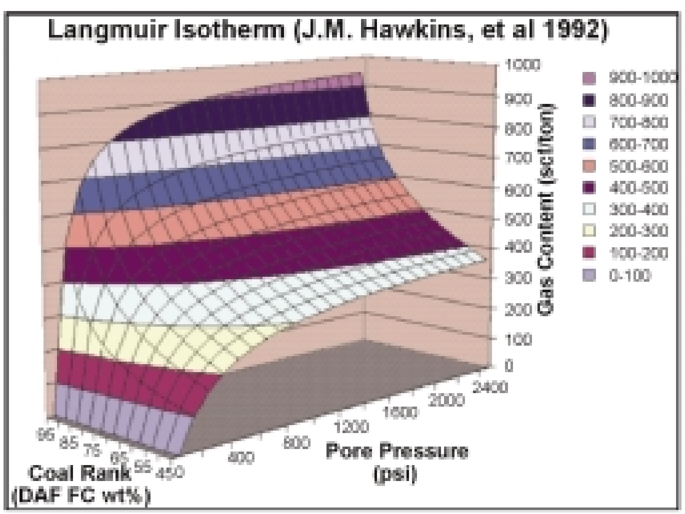


Figure 3. Langmuir Isotherm relating pore pressure, coal rank and gas content.

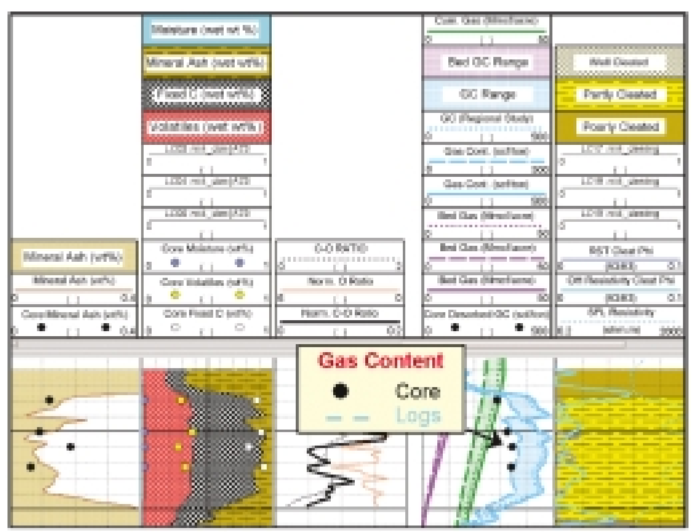


Figure 4. Advanced coal petrophysical interpretation, integrating log and core data.

Continued on page 40…

Tech Corner … *continued from page 39*

The typical procedure for measuring coal pore pressure and permeability is through-casing with bridge plug/gauges/buildup and/or injectivity-falloff testing. With a limited number of coals to test, this procedure may be desirable. However, if pressures are required in many potential coal seams, open or cased hole wireline testing may be a viable option.

Wireline formation testing has a long history in conventional reservoir testing. Coals present a new application for this proven technology. The key measurements provided are:

- Exact depth correlation,
- Very accurate pressure/time measurement,
- Sampling with extensive drawdown/monitor control.

Because of the mechanical properties of coals, dual inflate packers that straddle the interval are normally used. The raw data, combined with pressure transient analysis, provide both pressure and permeability of each individual, permeable seam.

Some of these wireline devices are capable of precision pressure and volume controlled wellbore fluid injection into the reservoir, allowing mini injectivity-falloff testing as well.

Permeability Indication: Shear Sonic

The most significant factors controlling coal permeability including those in Western Canada are:

- The stress acting within the coal seams,
- The intensity and extensiveness of fracturing in the coal seams,
- Secondary mineralization infilling coal cleat and fracture systems.

It has been thought for sometime now that stress may be a primary control on coal seam permeability, either directly by its impact on the relative "openness" of fractures existing in the coal at various scales, or indirectly by contributing to the development of fractures in the coal. McLennan et al (1994) reported that, during laboratory injection cycles where the principal stresses or the difference between them were relatively small, complex cleat or fracture networks developed. At elevated stress levels, on the other hand, single facture trends tended to dominate, accessing a much smaller volume of the reservoir.

In the Western Canadian example (Figure 5), three coals are illustrated, labeled 1, 2 and 3. When acoustic data is recorded in cross receiver mode (i.e. shear orthogonal to each other), anisotropy can be measured. Acoustic anisotropy is primarily either a condition of fractures or stress. In a coal seam, relaxed anisotropy can be a qualitative permeability indicator.

Offset energies, as seen as green in the depth track, is related to amplitude change when waveforms logged orthogonal to each other are rotated to a common angle. The more change between the minimum and maximum, the more anisotropy is present.

With the least amount of anisotropy, the coal at Marker 1 would have the best permeability as compared to the coal at Marker 3.

Optionally, velocity anisotropy can be computed to assist in advanced, oriented completions. The fast shear direction is that of the maximum horizontal stress and the direction of hydraulic fracture propagation. The example shows this direction to be 30 degrees East of North.

Shear sonic data can also be processed for rock mechanical properties and stress profiles. This stress analysis is based on factors including Young's modulus, Poisson's ratio, overburden

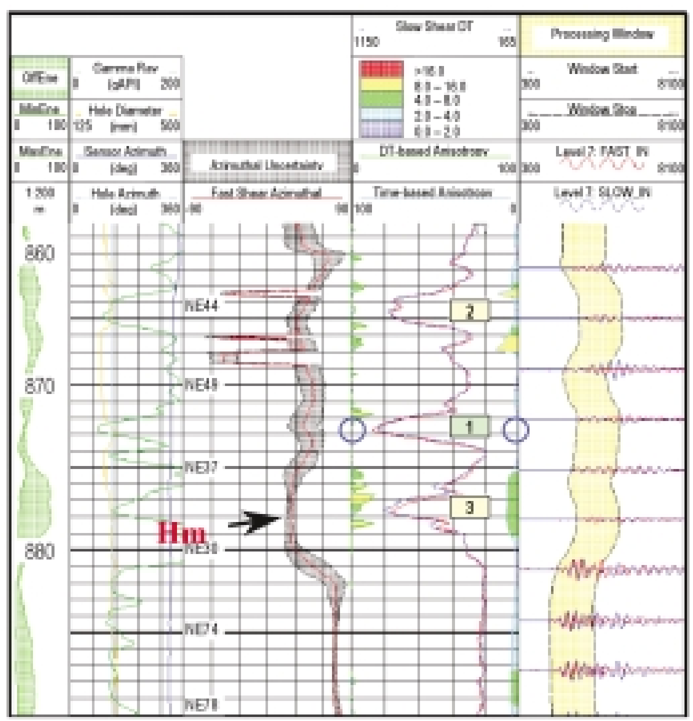


Figure 5. DSI Anisotropy illustrating Marker 1 having the least anisotropy and best expected permeability.

Continued on page 41…

Determination … *continued from page 40*

pressure, reservoir pore pressure and adjacent bed pore pressure. The results are very useful in evaluating coal stability and hydraulic fracturing. However, current rock models are not sophisticated enough to accurately model complex coal behavior during stimulation.

Structure, Fracture, Cleat Evaluation: Imaging

Coal outcrops provide extensive information on stresses and coal-fracture systems. In the subsurface, many operators rely on borehole imaging to determine the degree of cleating and natural fracturing within the coals; in some wells, shear fractures can be observed using borehole images.

Illustrated in Figure 6 is an example of an Alberta Plains coal outcrop, showing clear face and butt cleats.

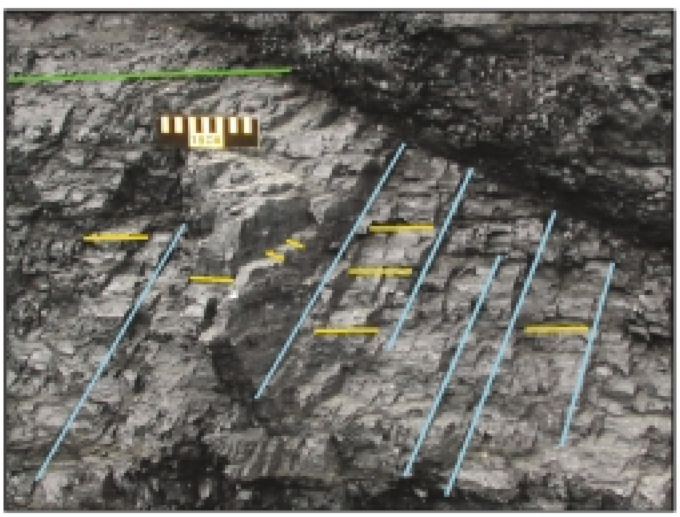


Figure 6. Alberta Plains coal outcrop showing face and butt cleats, bedding.
** Photo courtesy CSPG 2003*

Microresistivity electrical borehole images are generated from up to 192 microresistivity measurements. These measurements are acquired from multiple pads, oriented with respect to north and translated into an image rich in petrophysical and lithological information.

For one commercially available tool, the combination of measuring button diameter, pad design and high-speed telemetry system produces a vertical and azimuthal resolution of 5.1 mm (0.2 in.). This means that the dimensions of a feature larger than 5 mm can be fully resolved from the image. The size of features smaller than 5 mm is estimated by quantifying the current flow to the electrode. Fine details as small as 0.051mm (0.002-in) filled with conductive fluids are visible in microresistivity electrical borehole images, allowing identification of mega cleats and fractures.

The answers provided by the microresistivity tools help in:

- Understanding the reservoir structure,
- Identifying and evaluating sedimentary features and fractures,
- Visualizing rock texture,
- Complementing coring programs,
- Investigating and evaluating coal mega cleat systems.

The image of a plains coal in Figure 7 shows clear face and butt cleat development as well as bedding.

A major Canadian operator and their partners have acquired microresistivity electrical borehole data to determine cleat and fracture directions, as well as present-day stress orientation. This information is used in well planning and aids in the evaluation of hydraulic fracture stimulation behavior and effectiveness.

Drilling-induced fractures and borehole breakouts indicate orientation of in-situ stresses. Drilling induced features such as breakouts are readily identified.

High-quality borehole images of natural fractures facilitate interpretation of paleo-stress orientations and fracture apertures.

Borehole images also are used to orient and depth-match core, particularly in zones of poor core recovery.

Coal Samples: Wireline Rotary Coring

Wireline rotary sidewall coring tools provide an alternative in getting coal samples when full diameter core is not available.

The core plug dimensions are typically:

- Length: 50.8 mm (2.0 in.)
- Diameter: 23.4mm (0.92 in.)

When considering the rotary sidewall cores for gas content, proximate analysis, etc., the sample size must be taken into account. The recovery volume can limit usage. One major Canadian operator indicated the samples were quite suitable for typical coal analysis, including gas content.

Continued on page 42…

Tech Corner *… continued from page 41*

From the operational perspective, some rotary coring tools are quite successful in recovering coal rotary cores. Some “jamming off” can occur, requiring and additional descent into the well. Recovery success in the ninety percent range can be expected.

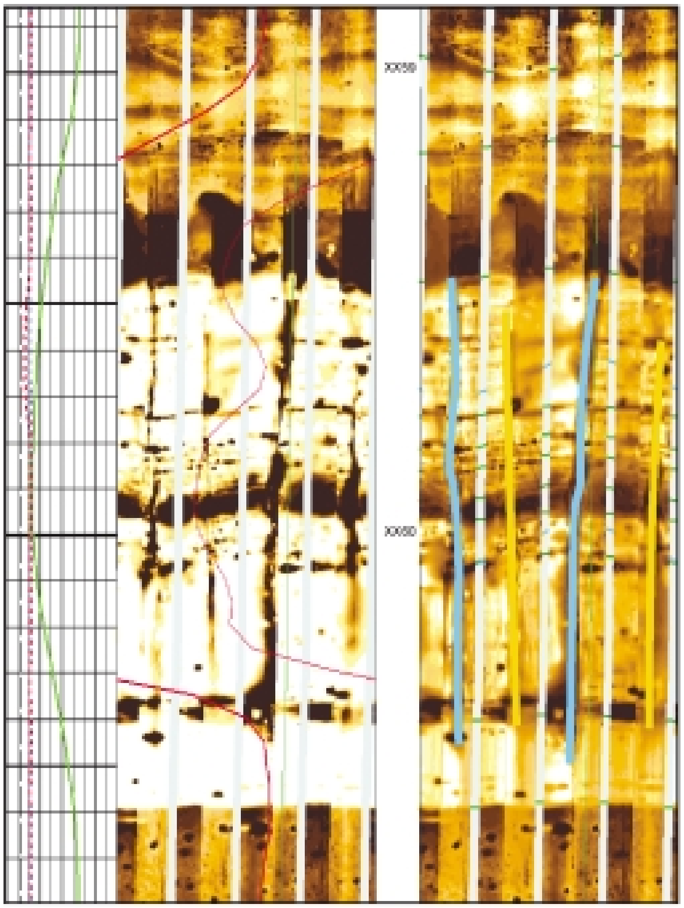


Figure 7. Alberta Plains coal outcrop showing face and butt cleats, bedding.

** courtesy Schoederbak & Ray, CSPG 2003*

Through Casing Production and Infill Well Evaluation

Formation Evaluation: Shear Sonic-Neutron-Gamma Ray

Modern shear sonic tools provide accurate formation compressional and shear slowness measurements in cased wells, providing a cost-effective, through casing, qualitative, evaluation option.

In coal zones, P velocities decrease dramatically (delta T compressional increases), the same as in open hole. If sands in the section are gas charged, again the compressional delta T increases, though not as significantly as in the coals. This is particularly evident through well-cemented casing where the gas has migrated directly behind the cement sheath.

When run with a compensated neutron and gamma ray, the combination works very well in:

- Identifying coal zones
- Determining coal zone thickness
- Qualitatively differentiating wet from gas charged sands

Each of the above factors can play a key role in CBM completion strategies.

The example in Figure 8 illustrates a coal-sand section in the Horseshoe Canyon in Central Alberta.

It is important to re-iterate that this evaluation option provides only a qualitative evaluation of the coal and sand resource.

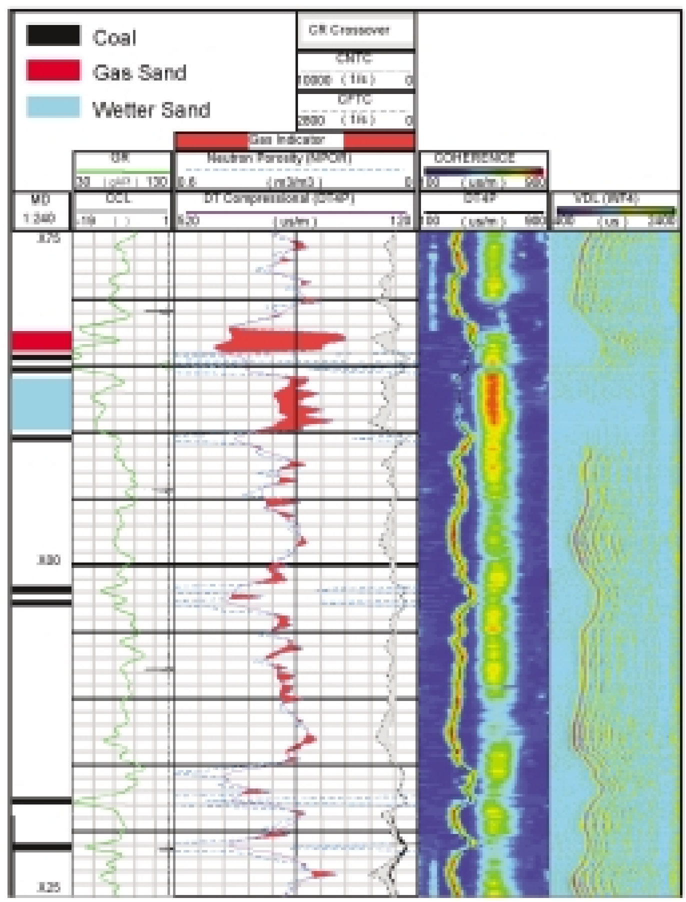


Figure 8. Shear Sonic-Compensated Neutron-Gamma Ray-CCL through casing in a Horseshoe Canyon coal-sand section, Central Alberta.

Continued on page 43…

Tech Corner *… continued from page 43*

Production Evaluation: Low Flowrate Production Logging

Production logging may be required to evaluate the effectiveness of the entire process: petrophysical interpretation, perforating strategy, stimulation type and execution, gathering system pressures, facilities design, etc. If so, two possible options exist:

- Low flow rate production log systems
- Higher technology, probe type sensors combined with more conventional sensors.

With a typical Horseshoe Canyon well producing at low rates from up to as many as 20-30 coal seams, measuring small contributions is important. At least one low flow rate production logging system available to the industry was specifically designed for 9 E3M3/day (300 MSCF/day) gas inflow rates. Individual seam contributions as low as 70 M3/day (2500 SCF/day) are resolvable. Typically in addition to the flow meter section, pressure, temperature and pseudo fluid density measurements are provided.

Figure 9 shows an example of a low flow rate system investigating a portion of a Horseshoe Canyon CBM well. Note the results using three different cable speeds show excellent repeatability, confirming inflow stability and system precision.

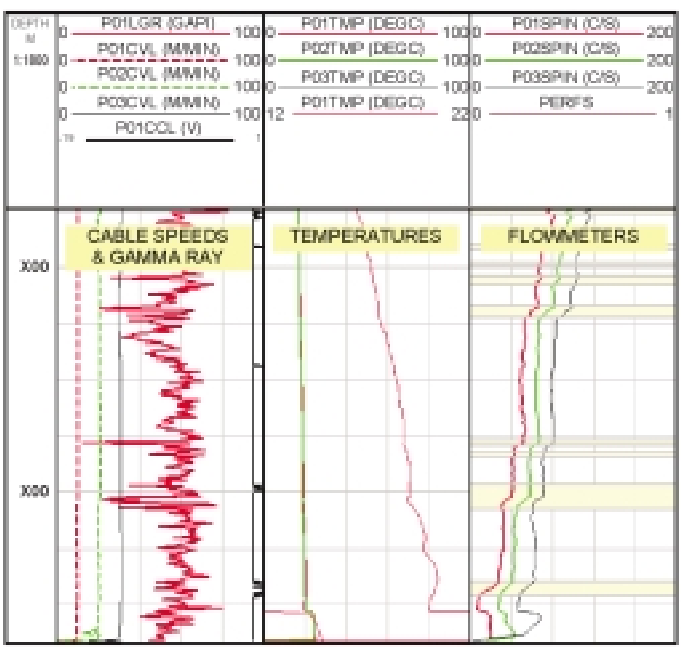


Figure 9. Low flow rate production logging system, illustrating pressure, temperature and turbine spinner over a portion of a dry Horseshoe Canyon CBM well.

With the more sophisticated, higher technology systems, traditional measurements such as pressure, temperature, density and spinner are redesigned to deliver improved accuracy and resolution. In addition, new sensors such as local electrical probes for holdup, collocated with the spinner and an integrated X-Y caliper, bring new and effective answers in complex flow regimes. The probe technologies are designed to directly distinguish gas from liquid, with high accuracy and resolution in multiphase wells. These devices can detect less than 1% gas in a liquid phase or 1% liquid in a gas phase. However, most of these systems currently have difficulty resolving some of the very small, individual seam contributions.

Realizing wet CBM wells will initially be on pump, inflow evaluation may not be initially possible. As water is removed, methane is liberated and gas rates begin stabilizing, production logging may be considered.

Summary

The challenges facing the petrophysical community in Coalbed Methane evaluation are significant. The purpose of this article was to help provide some insight into some of the measurements and interpretation techniques available. However, geology, hydrodynamics, perforating strategies, stimulation design and execution, gathering systems and facilities design too play critical roles in successful CBM projects.

Continuing measurement technology, interpretation expertise and experience development, combined with innovation and enthusiasm, are important for the future of our CBM industry.

Certainly one of the keys to economic CBM success will be in gathering appropriate data and capitalizing on lessons learned through an integration of all knowledge sources. Petrophysicists will play an essential role in the success of this exciting business opportunity.

John R. Kovacs, P.Eng.
Schlumberger Canada Ltd.
Coalbed Methane Champion
CWLS Past President 2003-2004

Productivity Estimation in the Milk River Laminated Shaly Sand, Southeast Alberta and Southwest Saskatchewan

E. R. (Ross) Crain, P.Eng. Spectrum 2000 Mindware
D. W. (Dave) Hume, P.Geol. Rakhit Petroleum Consultants Ltd

InSite apologizes for the errors in the figures in the previously printed paper in the December 2004 Issue.

See the following corrected figures.

METALOG HYDROCARBON SUMMARY RAKHIT MILK RIVER PROJECT

101112402119W3 Analyst: E.R. Crain, P.Eng. 28-Sep 2003

ZONE	ZN_TOP	ZN_BOT	PHIavg	SWavg	PERMavg	PV	HPV	KH	NetRes	VSHgross	NetCoal	CoalSh
			SHALY SAND			CONVENTIONAL MODEL "A"						
U_ALD	218.2	299.0	0.138	0.44	0.7	11.79	6.63	56	85.3	0.31	2.5	0.08
L_ALD	299.0	375.0	0.127	0.50	0.5	4.56	2.27	17	36.8	0.49	0.0	0.00
1WSP	375.0	396.0	0.094	0.87	0.1	0.15	0.02	0	2.8	0.60	0.0	0.00
1WSP_BASE	396.0											
CORE_TOP	299.0	343.0	0.131	0.47	0.5	5.93	3.12	24	45.3	0.37	0.5	0.17
CORE_BASE	343.0	Core Avg	0.242		NA							
IP_e3m3	1145.1	Est Prod	309.1	e3m3 estimated from KH over perfed interval								
CUM_e3m3	2971.0			with frac multiplier =		2.0						
PERF	258.0	333.0	0.138	0.43	0.7	9.09	5.68	49	71.2	0.31	1.4	0.08

ZONE	ZN_TOP	ZN_BOT	PHIavg	SWavg	PERMavg	PV	HPV	KH	NetRes	VSHgross	NetRes with Q1>=5	Q1>=4
			SHALY SAND			LAMINATED MODEL "B"						
U_ALD	218.2	299.0	0.138	0.44	0.7	8.50	4.79	41	61.7	0.31	71.5	82.6
L_ALD	299.0	375.0	0.127	0.50	0.5	5.16	2.57	19	48.7	0.49	23.3	35.4
1WSP	375.0	396.0	0.094	0.87	0.1	0.60	0.08	0	6.4	0.60	0.0	0.8
1WSP_BASE	396.0											
CORE_TOP	299.0	343.0	0.131	0.47	0.5	4.45	2.34	18	34.8	0.37	32.3	43.1
CORE_BASE	343.0	Core Avg	0.242		NA							
IP_e3m3	1145.1	Est Prod	225.5	e3m3 estimated from KH over perfed interval								
CUM_e3m3	2971.0			with frac multiplier =		2.0						
PERF	258.0	333.0	0.139	0.43	0.7	7.21	4.14	36	51.9	0.31	59.7	69.6

ZONE	ZN_TOP	ZN_BOT	PHIavg	SWavg	PERMavg	PV	HPV	KH	NetRes	VSHgross	NetRes with Q1>=5	Q1>=4
			CLEAN SAND			LAMINATED MODEL "C"						
U_ALD	218.2	299.0	0.194	0.30	3.6	11.99	8.44	222	61.7	0.31	71.5	82.6
L_ALD	299.0	375.0	0.176	0.45	1.7	7.18	3.98	65	48.7	0.49	23.3	35.4
1WSP	375.0	396.0	0.151	0.71	0.6	0.96	0.28	4	6.4	0.60	0.0	0.8
1WSP_BASE	396.0											
CORE_TOP	299.0	343.0	0.190	0.33	3.0	6.45	4.29	101	34.8	0.37	32.3	43.1
CORE_BASE	343.0	Core Avg	0.242		NA							
IP_e3m3	1145.1	Est Prod	1176.0	e3m3 estimated from KH over perfed interval								
CUM_e3m3	2971.0			with frac multiplier =		2.0						
PERF	258.0	333.0	0.194	0.30	3.6	10.08	7.08	186	51.9	0.31	59.7	69.6

ZONE	ZN_TOP	ZN_BOT	PHIavg	SWavg	PERMavg	PV	HPV	KH	NetRes	VSHgross	NetRes with Q1>=5	Q1>=4
	RESPONSE EQUATION		CLEAN SAND			LAMINATED MODEL "D"						
U_ALD	218.2	299.0	0.350	0.17	2000.0	21.61	18.00	*********	61.7	0.31	71.5	82.6
L_ALD	299.0	375.0	0.195	0.31	3.7	7.95	5.49	151.8	48.7	0.49	23.3	35.4
1WSP	375.0	396.0	0.123	0.59	0.2	0.78	0.32	1.1	6.4	0.60	0.0	0.8
1WSP_BASE	396.0											
CORE_TOP	299.0	343.0	0.275	0.20	109.1	9.38	7.46	3737.4	34.8	0.37	32.3	43.1
CORE_BASE	343.0	Core Avg	0.242		NA							
IP_e3m3	1145.1	Est Prod	175243	e3m3 estimated from KH over perfed interval								
CUM_e3m3	2971.0			with frac multiplier =		2.0						
PERF	258.0	333.0	0.313	0.18	832.9	16.25	13.48	276703.6	51.9	0.31	59.7	69.6

Figure 5: Sample Net Reservoir calculations for four shaly sand models.

METALOG ANALYSIS

121111202318W300

PERF INTERVAL FOR Q1 >= 4			PERF INTERVAL Vsh <= 0.65			PERF INTERVAL ACTUAL		
PRF TOP	PRF BOT	NET INTR	PRF TOP	PRF BOT	NET INTR	PRF TOP	PRF BOT	NET INT
540.9	541.8	0.9	541.1	541.6	0.5			0.0
531.0	531.1	0.1	531.0	531.1	0.1			0.0
478.8	479.4	0.6	478.2	479.3	1.1	477.0	479.0	2.0
464.0	464.3	0.3	464.1	464.3	0.2			0.0
463.4	463.7	0.3	457.3	457.4	0.1			0.0
462.1	462.2	0.1	389.2	389.4	0.2			0.0
457.3	457.7	0.4	386.4	387.6	1.2	384.0	388.0	4.0
389.1	389.5	0.4	385.2	385.9	0.7			0.0
386.2	387.7	1.5	381.4	382.4	1.0	381.0	383.0	2.0
385.1	386.1	1.0	378.2	379.6	1.4			0.0
381.4	382.4	1.0	376.1	376.6	0.5	375.0	380.0	5.0
378.2	379.6	1.4	375.7	376.0	0.3			0.0
375.6	376.7	1.1	371.3	371.6	0.3	370.0	371.0	1.0
371.3	371.7	0.4	370.0	370.8	0.8			0.0
370.0	370.8	0.8	369.1	369.3	0.2			0.0
369.0	369.4	0.4	366.2	366.5	0.3	366.0	367.0	1.0
368.3	368.4	0.1	365.6	365.8	0.2			0.0
366.2	366.7	0.5	354.7	355.2	0.5	353.0	355.0	2.0
365.5	366.1	0.6	352.0	353.0	1.0			0.0
364.9	365.0	0.1	350.4	351.4	1.0	350.5	351.5	1.0
364.7	365.2	0.5	348.9	350.2	1.3	345.0	350.0	5.0
352.0	353.1	1.1	345.2	345.3	0.1			0.0
350.3	351.4	1.1	338.6	340.0	1.3	338.0	342.0	4.0
348.8	350.2	1.4	336.1	337.1	1.0			0.0
347.7	347.9	0.2	334.4	334.6	0.2	333.0	334.0	1.0
345.2	345.4	0.2	330.7	332.0	1.3			0.0
343.1	343.4	0.3	327.1	327.6	0.5			0.0
341.1	341.5	0.4	333.1	333.3	0.1			0.0
338.4	340.6	2.2	318.7	320.2	1.5			0.0
336.1	337.1	1.0	317.3	317.4	0.1			0.0
334.4	334.7	0.3	316.3	316.9	0.6			0.0
333.4	333.7	0.3	314.2	315.5	1.3			0.0
330.0	332.1	2.1	311.8	312.8	1.0			0.0
327.1	327.6	0.5	310.1	311.1	1.0			0.0

Figure 6: Portion of unfiltered perforation list generated by the prototype program

Continued on page 41…

Productivity Estimation … *continued from page 26*

META/LOG ANALYSIS RESULTS Milk River Project

Well Location	Averagge Porosity Over Cored Interval Log	Averagge Porosity Over Cored Interval Core	Perfed Interval	Actual IP_E3M3 1st 3 MO	Est Prod 1st 3 MO 2x Frac Multiplier	PV	HPV	KH	NetRes	VShaeg	Q1>=5	Q1>=4
						Over Perfed Interval	Over Perfed Interval	Over Perfed Interval	Over Perfed Interval	Over Perfed Interval		
100/04-03-015-03W4/00	0.175	0.137	0.179	341.3	235.4	3.52	2.03	37	19.7	0.47	4.1	15.5
100/06-26-015-14W4/00			0.198	77.5	58.4	0.59	0.39	9	3.1	0.37	4.1	5.0
100/07-36-018-10W4/00	0.170	0.126	0.173	181.5	236.9	4.42	2.32	37	25.5	0.51	6.0	20.6
100/08-13-022-16W4/00	0.165	0.039	0.171	254.8	150.3	3.01	1.53	24	17.6	0.52	0.0	10.5
100/14-28-018-07W4/00	0.153	0.138	0.158	133.9	116.6	3.56	1.39	18	22.4	0.59	1.4	6.6
100/16-27-020-16W4/00	0.161	0.094	0.162	56.7	98.0	2.70	1.14	15	16.7	0.57	0.2	5.6
101/11-24-021-19W3/00	0.190	0.242	0.194	1416.7	1176.0	10.08	7.08	166	51.9	0.31	59.7	69.6
102/08-08-020-17W4/00	0.182	0.109	0.192	144.8	379.2	3.57	2.43	60	18.6	0.35	34.5	28.8
102/10-27-018-01W4/00	0.169	0.145	0.168	87.9	147.9	3.17	1.55	23	18.5	0.54	3.0	12.6
100/06-20-015-11W1/00	0.190	0.149	0.189	383.1	483.3	4.99	3.29	76	26.4	0.37	20.1	24.4
100/06-27-016-09W4/00			0.198	673.9	1035.9	10.52	6.98	164	55.5	0.37	57.3	76.7
100/06-29-023-03W4/00			0.173	31.5	148.2	2.77	1.45	23	16.0	0.51	3.4	12.8
100/07-27-020-16W4/00			0.163	176.8	114.5	3.07	1.32	18	18.8	0.57	0.3	6.4
111/06-04-023-17W3/00			0.198	472.6	741.2	5.33	4.03	117	26.8	0.18	5.6	10.8
111/11-32-021-19W3/00			0.186	1190.3	1135.9	13.31	8.41	179	71.7	0.41	62.3	97.7
121/06-18-018-25W3/00			0.168	118.4	120.0	2.88	1.33	19	17.3	0.55	0.7	6.5
141/11-11-021-19W3/00			0.192	1541.2	1497.9	14.12	9.60	237	73.7	0.35	86.6	104.4
AVERAGE 17 WELLS	0.174	0.140	0.179	428.4	483.3	5.39	3.31	73	29.4	0.44	20.0	30.2

Figure 8A: Numerical data for initial production comparison

META/LOG ANALYSIS TOPS and TESTS Milk River Project

Long Well ID	KB Elev	U_ALD	L_ALD	1WSP	1WSP_BASE	CORE_TOP	CORE_BASE	IP_E3M3 1st 3 MO	CUM_E3M3	PERF TOP	PERF BASE
CORED, PERFED, PRODUCED - CALIBRATION WELLS											
100/04-03-015-03W4/00	744.3	337.1	378.0	436.5		354.2	416.7	341.3	11328	377.3	414.5
100/06-26-015-14W4/00	747.6	273.0	315.0	361.0	373.0			77.5	452	277.0	282.0
100/07-36-018-10W4/00	768.9	320.0	363.9	417.6		365.8	384.1	181.5	7420	350.5	402.9
100/08-13-022-16W4/00	733.5	392.0	437.0	484.0	502.0	394.9	478.9	254.8	8801	418.5	528.0
100/14-28-018-07W4/00	776.8	346.0	396.0	450.0		352.0	442.0	133.9	4530	379.1	433.4
100/16-27-020-16W4/00	770.2	402.3	447.4	495.6		448.4	458.1	56.7	3769	428.5	467.6
101/11-24-021-19W3/00	680.3	210.2	299.0	379.0	396.0	289.0	343.0	1416.7	2971	258.0	333.0
102/08-08-020-17W4/00	791.4	443.0	489.0	526.0	554.0	467.3	509.0	144.8	936	402.0	573.0
102/10-27-018-01W4/00	751.6	358.1	420.6	479.1		411.5	429.8	87.9	5156	411.2	451.7
PERFED, PRODUCED - MODEL TESTING WELLS											
100/06-20-015-11W1/00	748.8	262.1	284.8	295.7	304.2	294.1	318.5	383.1	9007	282.5	325.0
100/06-27-016-09W4/00	773.0	304.8	348.7	399.3	417.9			673.9	24594	331.3	625.4
100/06-29-023-03W4/00	736.7	344.4	408.4	466.6	490.4			31.5	70.1	395.6	428.5
100/07-27-020-16W4/00	763.5	396.2	443.2	487.7	445.0			176.8	7137.5	446.2	462.1
111/06-04-023-17W3/00	597.1	234.0	309.0	411.0	433.0			472.6	323.6	320.5	353.0
111/11-32-021-19W3/00	594.7	225.5	315.0	395.0	410.0			1190.3	2794	231.5	354.0
121/06-18-018-25W3/00	719.0	344.4	417.5	478.0	494.0			118.4	4129.8	401.7	440.4
141/11-11-021-19W3/00	609.9	239.8	330.0	409.0	425.0			1541.2	3611	246.0	359.0
AVERAGE 17 WELLS	718.1	319.6	376.6	433.6	308.5	375.2	420.0	428.4	5707.7	350.4	425.5

Figure 8B: Stratigraphic data for initial production comparison

UPCOMING EVENTS

March 2, 2005

CWLS TECHNICAL LUNCHEON PRESENTATION

Fairmont Palliser Hotel, Calgary, AB

Satyaki Ray, Schlumberger Data and Consulting Services

Fracture Characterization in Low Permeability Reservoirs

March 13 – 17, 2005

SPWLA SPRING TOPICAL CONFERENCE

Kananaskis, AB

Unconventional Reservoirs, Resolving the Formation Evaluation Challenge in Fractured, Tight Gas and Shale Gas Reservoirs

April 13, 2005

CWLS TECHNICAL LUNCHEON PRESENTATION

Fairmont Palliser Hotel, Calgary, AB

Steve Cuddy, Helix RDS

The Application of Novel Formation Evaluation Techniques to Complex Tight Gas Reservoirs

June 19 – 22, 2005

AAPG 2005 ANNUAL CONVENTION

Calgary, AB

Exploring Energy Systems www.aapg.org/calgary

June 26 – June 29, 2005

46TH ANNUAL SPWLA SYMPOSIUM

New Orleans, LA, USA

Corporate Members are:

Platinum

Anadarko Canada Corporation
Encana Corporation
IHS Energy
Precision Wireline Technologies

Gold

Baker Atlas
Burlington Resources Canada Ltd.
Conoco Philips Canada
Continental Laboratories (1985) Ltd.
Devon Canada
Husky Energy Inc.
Petro-Canada Oil & Gas
Schlumberger of Canada
Shell Canada Limited
Talisman Energy Inc.
Wellsite Gas Detection Inc.

Silver

Delta P Test Corporation
Qercus Resources Ltd.
Sproule Associates Limited
Tucker Wireline Services

Bronze

Apache Canada Ltd.
Blade Ideas Ltd.
Core Laboratories Canada Ltd.
ECL Exploration Consultants Ltd.
GeoLOGIC Systems Ltd.
Halliburton Energy Services
HEF Petrophysical Consulting Inc.
Landau Petroleum Ventures Inc.
LogTech Canada Ltd.
Nexen Canada Ltd.
NMR Petrophysics, Inc.
Paradigm Geophysical
Paramount Resources Ltd.
Plains Perforating Ltd.
Reeves Wireline
Roke Oil Enterprises Ltd.
Suncor Energy Inc.
Taggart Petrophysical Services Inc.

The CWLS is pleased to have donated copies of our "Publications on CD" to:

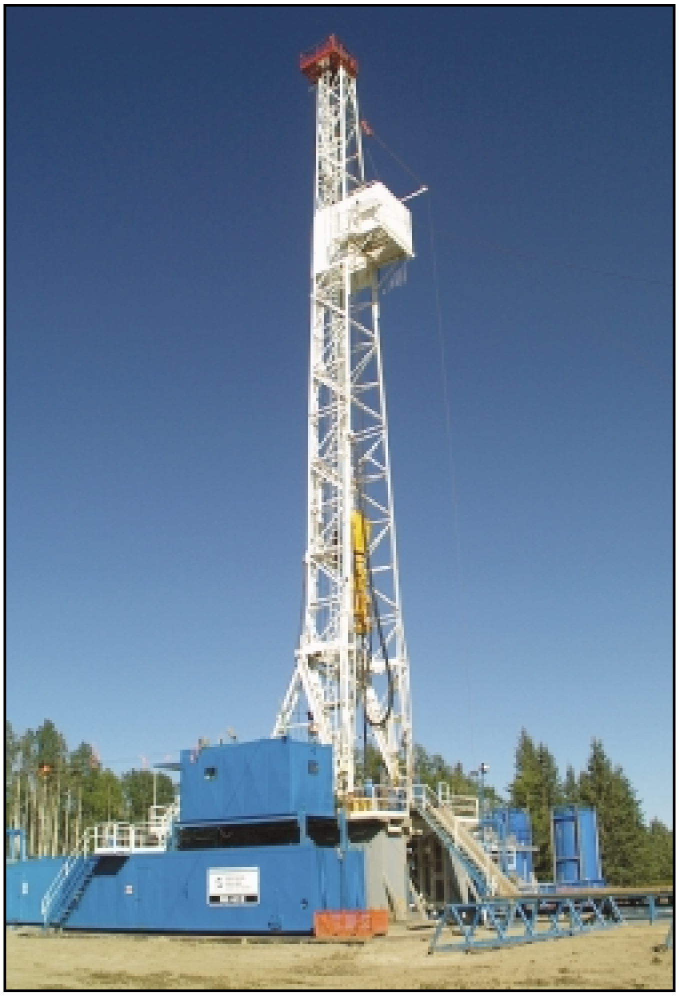
- University of New Brunswick – Science and Forestry Library
- Baghdad University

If any other schools are interested in complimentary copies please contact: Robert_Bercha@anadarko.com

The CWLS has donated a 2002 R_w CD to:

School of Mining and Petroleum Engineering, Department of Civil and Environmental Engineering, University of Alberta.

The students had been using the 1987 Rw Catalog and were happy to receive the updated version.



Drilling operations south of Rocky Mountain House, AB.
Photos Courtesy Bruce Greenwood.

Rig Move operations in the Brazeau Area, AB.
Photo Courtesy Scott Hadley

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

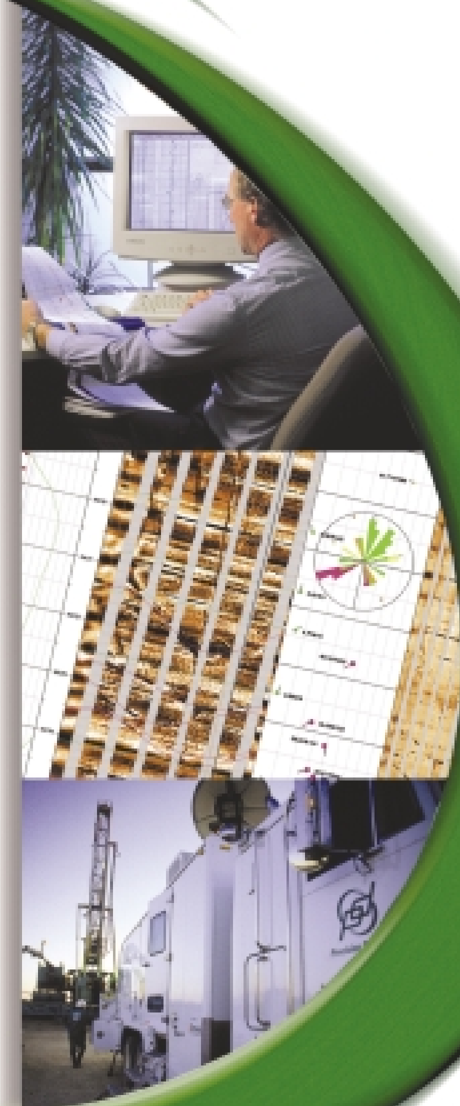
Drilling operations in the Resthaven Field near Grande Cache, AB.
Photo Courtesy Gerry Pasveer

CANADIAN WELL LOGGING SOCIETY
Scotia Centre 2200, 700 – 2nd Steet S.W., Calgary, Alberta T2P 2W1
Telephone: (403) 269-9366 Fax: (403) 269-2787
www.cwls.org

Open-Hole Logging

Cased-Hole Logging and Perforating

Slickline



Precision Drilling Corporation is a global oilfield services company with a rich history in Canada. A history of giving customers more than you expected. Responding quickly to your requests. Adapting readily to your requirements. And most importantly, remaining attentive to your changing needs. Outstanding people. Fit-for-purpose technologies. Exceptional performance. That's what Precision brings to you. Because when your oilfield services company is committed to giving you the best, you get more than just good service – you get **precisely what you need**.

Precision Drilling

www.precisiondrilling.com