

2 Exploration Applications of
the Multipole Acoustic Log:
A Case Study

7 Chairman's Remarks
Members on the Move

8 Society News

President's Remarks



The "Geo-Triad 98" symposium was a resounding success with record attendance (5,000+) from all facets of the exploration and production community. I would like to pass on a hearty thank you to Winston Karel and Monty Ravlich, who represented the CWLS as co-chairman and advisor, also to the many members who volunteered their time in the CWLS booth.

The next major initiative that the society will be involved with is the "GeoCanada 2000" symposium slated for Calgary in the spring of the year 2000. The CWLS co-chairman on the planning committee is Glenn Gray (234-9144) and he is looking for volunteers for a wide variety of duties.

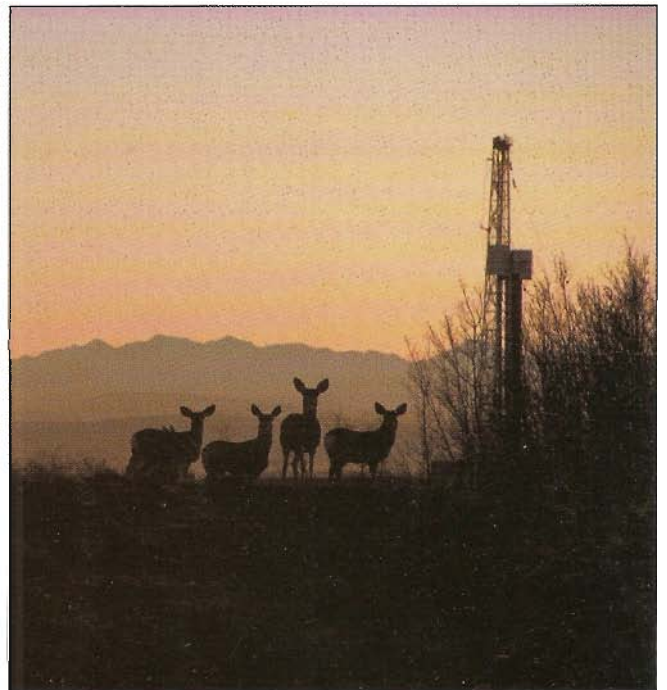
The nomination's committee is looking for candidates to run for executive office for the 1999 - 2000 year. Please contact any member of the present executive if you are interested, as nominations will be closed at the December 16, 1998 luncheon.

CWLS members and guests enjoyed a fine evening on November 10, 1998 as the society hosted a reception in the Palliser penthouse. The high point of the evening was the presentation of a cheque for \$73,750.00 by Mssr's. Karel and Ravlich representing the CWLS proceeds from the "Geo-Triad 98". The admission monies to the reception were donated to the "Children's Cottage" to aid them in their work in our community.

I wish you all a busy and prosperous winter season.

Yours sincerely,

James S. Prior
President, CWLS



GeoCanada 2000 ...the Millennium Summit

GeoCanada 2000 is a joint meeting of Canada's major societies, including the Geological Association of Canada (GAC), the Mineralogical Association of Canada (MAC), the Canadian Society of Petroleum Geologists (CSPG), the Canadian Society of Exploration Geophysicists (CSEG), the Canadian Well Logging Society (CWLS) and others. To be held at the University of Calgary, **May 29 - June 2, 1999**

Exploration Applications of the Multipole Acoustic Log: A Case Study

Lee Hunt, Calahoo Petroleum Ltd. and Glen Horel, Baker Atlas

Abstract

This paper will illustrate the role of the full waveform acoustic log as a useful tool in the exploration cycle of the example well. This cycle, as illustrated in figure 1 below, includes the petrophysical evaluation of a newly drilled location, the seismic inversion work that was used to identify this location, and the seismic modeling that was used to validate the inversion and complete the cycle.

dipole tool, full waveforms are recorded that, despite slow formation velocities, will include compressional and shear information. These waveforms are put through an Nth root correlation algorithm to produce compressional and shear slowness values.

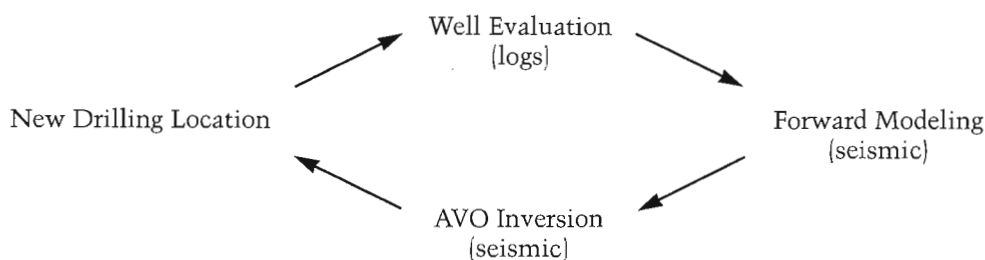


Figure 1.

An anomaly was identified on a 2-D seismic line and an interpretation was made based on AVO (Amplitude Variation with Offset) inversion. However, AVO inversion has many uncertainties associated with it and the AVO response does not uniquely determine the geology. Despite efforts to predict the geologic nature of the anomaly, some question remained regarding the veracity of the interpretation and the AVO inversion. The location was drilled and a full waveform multipole array acoustic log was run to verify the validity of the seismic analysis and as a petrophysical aid in determining if the reservoir was gas bearing. With the use of the multipole acoustic data, a productive gas zone was found and cased and the seismic ambiguities were resolved.

Introduction

For a number of years now, multipole full waveform compressional and shear acoustic logs have been available to E&P companies. Using the Baker Atlas Multipole Array Acoustic (MACTM) tool, Calahoo Petroleum Ltd. acquired shear and compressional slowness data on its Enchant well at 3-13-14-18W4 in Alberta. The various applications of this MAC data in Calahoo's E&P efforts are the focus of this paper.

A limitation exists in acoustic logging with the use of standard, omnidirectional, monopole sources where no shear mode will be recorded if the formation shear velocity is less than the velocity of the mud in the borehole. Dipole acoustic tools were designed to get around this limitation. The MAC tool, and the next generation Cross-Multipole Array Acoustilog (XMACTM) tool, incorporates two monopole transmitters and two dipole transmitters, each with an array of 8 receivers. With the use of a

Typically, compressional slowness values are used for porosity calculations and as an aid in lithology determination. Shear data can be used for rock property calculations for hydraulic stimulation. Utilizing the well-understood effect of gas on acoustic results, it is possible to go beyond these basic applications.

The introduction of a small amount of gas in the pore spaces of clastic rocks causes a large increase in compressional slowness and a small decrease in shear slowness. That is, a clastic rock with some gas saturation will exhibit anomalously low ratio values of shear to compressional slowness (low SCRA or V_p/V_s). It is the relatively high compressibility of the gas that is the fundamental driver of this effect. Only small quantities of gas (low gas saturations) are needed to cause a V_p/V_s anomaly (figure 2). This acoustic gas effect is most obvious in clastic rocks and becomes more pronounced in younger, less consolidated formations. Gas effects become ambiguous in framework dominated rocks such as carbonates and acoustically fast clastics ($DTS < 425$ usec/m). Both petrophysical and seismic techniques, which rely on this acoustic gas effect, were used to evaluate the well in question.

D.M. Williams (1990) proposed the Acoustic Log Hydrocarbon Indicator (ALHI), which employs a crossplot of SCRA (V_p/V_s) versus shear slowness (DTS). Shales and water bearing sands plot along a background trend from lower-left to upper-right on the crossplot. Due to low SCRA values, gas-bearing sands will tend to stand alone below the background trend. The ALHI technique was applied to the Enchant well as a petrophysical aid to help identify potential gas bearing intervals (figure 3).

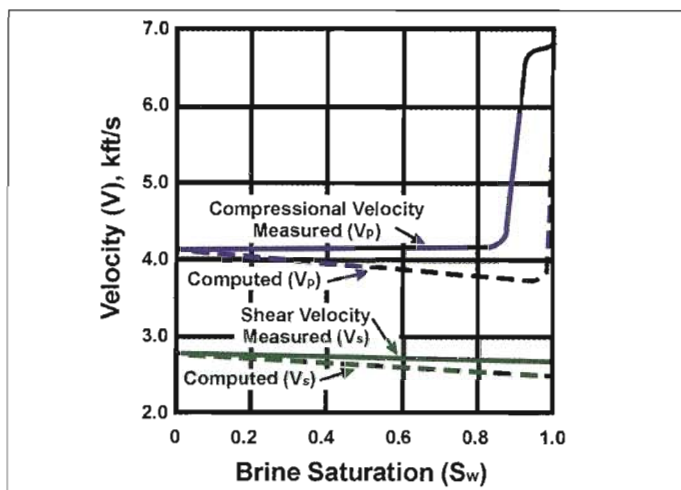


Figure 2. Measured P and S-wave velocities versus water saturation. The dashed lines are a theoretical calculation from Biot (1956). Diagram from Tatham & McCormack (1991)

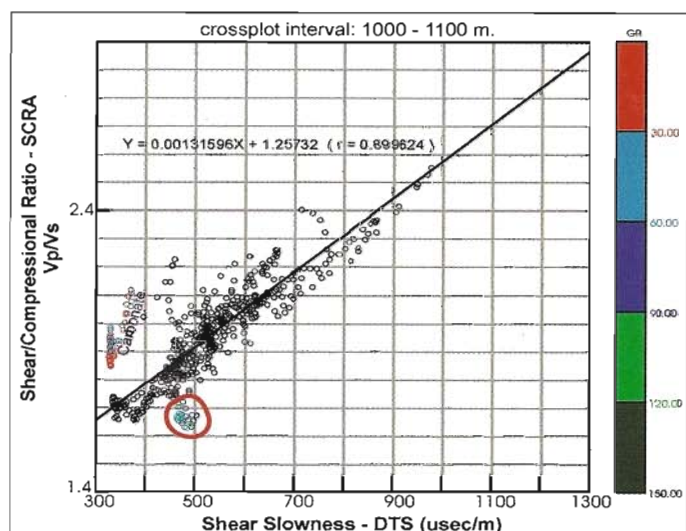


Figure 3. Acoustic Log Hydrocarbon Indicator (ALHI) plot. Data points within the red circle are ALHI gas flag indicators (see figure 6)

The exploration use of well logs has always extended beyond the evaluation of reservoir quality and fluid content in a particular well bore. Geophysicists have traditionally made use of well logs for the reciprocal purposes of forward and inverse modeling. Forward modeling is an experiment where the geologic parameters of velocity and density are input to an algorithm, which creates a model of the seismic response. Forward modeling is used to help the geophysicist identify the seismic response of a wide variety of geological scenarios. This method is limited by the sophistication and appropriateness of the modeling algorithm as well as the geophysicist's choice of input parameters; which originate from the well log data. Inverse modeling is an experiment that attempts to take a seismic

response, and by use of an algorithm, estimate the earth parameters responsible for the seismic image observed. There are usually several non-unique possible causes for any particular seismic response, so the geophysicist often imposes a constraint to drive the model in an appropriate direction. The appropriateness of the constraint critically determines the validity of the inversion experiment. It is for this reason that the compressional velocity and formation density information from well logs are important elements of the inversion method. Both of these modeling methods help the geophysicist make appropriate estimates of the meaning of the seismic data, and ultimately lead to the analysis and subsequent drilling of exploration and development prospects.

The acoustic gas effect discussed earlier has also been of special interest to geophysicists, and has led to a resurgence in interest in the seismic methods of amplitude versus offset analysis, or AVO, and AVO inversion. These two related seismic methods attempt to estimate elastic earth parameters by solving the Zoeppritz equations. These equations quantify information about both the shear and the compressional reflection velocities of the earth from standard multi-offset compressional data. AVO methods may yield data that is vastly more useful to exploration, but it is well known that it is also much more difficult to obtain results that have a satisfactory level of integrity. It is for this reason that the methods of forward and inverse modeling, long used in conventional seismic exploration, are of even greater importance in the overall scheme of AVO methodology. The elastic earth properties of compressional and shear wave velocity available in the full waveform acoustic log are important as input data for the forward modeling and as constraints for the inverse modeling, and are therefore crucial to the AVO methods being discussed.

The Zoeppritz equations are very complex, and have been simplified into several shorter forms that find use in current AVO methodologies. These short forms all essentially analyze the multi-offset seismic gather as having an amplitude at zero offset or angle, called the intercept value, and having a rate of change of amplitude with angle, called the gradient. Analysis of the intercept and gradient terms gives information about the elastic rock properties of the imaged subsurface. In recent work by Gidlow et al (1992), it was shown that the compressional and shear wave reflectivity may be estimated from the intercept and gradient, respectively. It should be noted that the extraction of the reflectivity sequences does require some basic knowledge about the compressional and shear wave velocities in the area as well as the densities.

Goodway et al (1997) revealed an extension to Gidlow's work in which they extracted Lamé's parameters from an inversion of the compressional and shear wave reflectivities. The Lamé's parameters are very useful in geophysical prospecting because

they may be used to interpret fluid type and lithology. Goodway's method is outlined below:

1. Perform AVO analysis using Gidlow's method to obtain the compressional and shear reflectivities.
2. Perform an inversion on each reflectivity sequence to obtain the compressional impedance I_p , and the shear impedance I_s .
3. Manipulate these results to obtain Lamé's parameters:

$$\lambda\rho = I_p^2 - 2 I_s^2$$

$$\mu\rho = I_s^2$$

where $\lambda\rho$ (lambda-rho) is the incompressibility multiplied by the density, and $\mu\rho$ (mu-rho) is the rigidity of the rock multiplied by the density.

The incompressibility of the rock is effected by the presence of fluid, particularly gas, while the rigidity of the rock is dependent on the rock matrix. Gas sands are characterized by low values of lambda-rho and low lambda-rho over mu-rho ratios. In performing this analysis, the geophysicist is attempting to make a similar analysis on the seismic data as the petrophysicist makes with the full waveform acoustic log and the ALHI technique.

Limitations of AVO Techniques: A Need for Compressional and Shear Wave Velocity Data

The AVO inversion method as outlined above may seem to be a simple solution to seismic interpretation in clastics, but unfortunately the correct application of this technique is very difficult. Seismic data has an abundance of noise, and a level of complexity that make the AVO analysis very difficult to perform accurately. Scaling of the gathers with offset is a critical issue. Having a nearby full waveform acoustic log and a density log can be helpful in the AVO processing and data conditioning sequence. The full waveform data, together with the density log can be used to create a multi-offset forward model. This model can be used to help qualitatively calibrate the conditioning and processing of actual AVO gathers. The full waveform data can also be used to help calibrate the AVO equation being used, which requires a basic knowledge of the compressional and shear velocities. In many cases, unexpected drilling results occur despite the most rigorous work. Recording a full waveform acoustic log may allow the geophysicist to investigate any possible error in the AVO analysis.

A nearby full waveform acoustic log may be useful as a constraint for the inversion itself. Inversion techniques often need to be constrained in order for the results to have stability, resolution, and greater uniqueness. The inherently unstable AVO inversion method clearly requires an appropriate constraint.

Discussion

Calahoo Petroleum Ltd. recently drilled a cretaceous gas well in southern Alberta. The location was picked as a result of AVO inversion work that was performed on a 2-D seismic line. There was a lack of full waveform data in the area, so Calahoo recorded Baker Atlas's MAC tool to better evaluate the drilling results and the accuracy of the geophysical work. The seismic section with the well location marked is shown in figure 4. There is a significant amplitude increase in the trough just above the Mississippian level at about 0.75s. AVO inversion was performed on the seismic yielding the lambda-rho estimate illustrated in figure 5a. The low values of lambda-rho at 0.75s suggested the strong possibility of a gas sand at the well location. The large time-width of the anomaly was also important because there also exists a regional Ostracod shale in the area that could have low lambda-rho values. The Ostracod shale in the area is typically only three or four meters thick, while a gas sand could be more than ten meters thick. An inverse modeling experiment was performed to determine whether the anomaly was more likely to be caused by an Ostracod shale or a thick gas sand based on this difference in thickness. In this experiment, the inversion was performed twice: once with a constraint that drove the solution towards an Ostracod shale solution, while the other inversion had a constraint that drove the solution towards thick gas sand. The results of this experiment are shown in figures 5a and 5b. The inversion results look similar for each case. Both solutions tend towards the prediction of a thicker anomaly than the Ostracod shale constraint. The data resisted being driven towards any solution where the anomalous zone was thin. This work lead to the prediction of a thick gas sand at the prospect rather than the Ostracod shale.

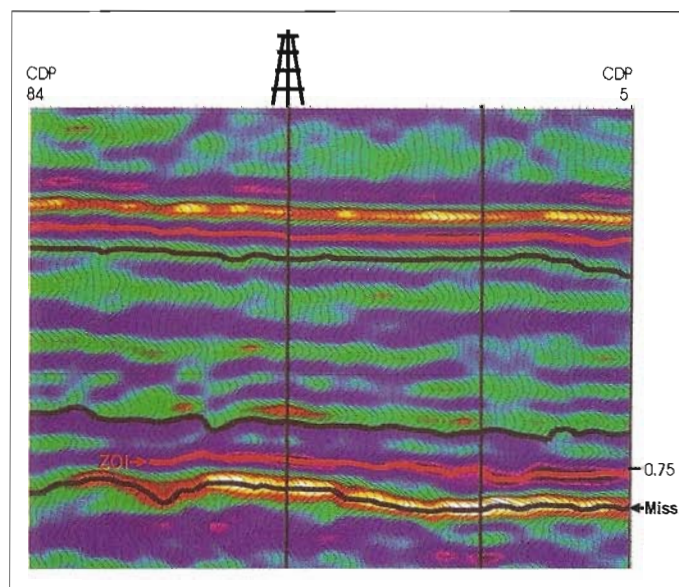


Figure 4. Surface seismic line. The zone of interest (ZOI) is the lower marker identified with the red line. Note the strong amplitudes of the trough in the ZOI become weaker near the end of the line (cdp 84)

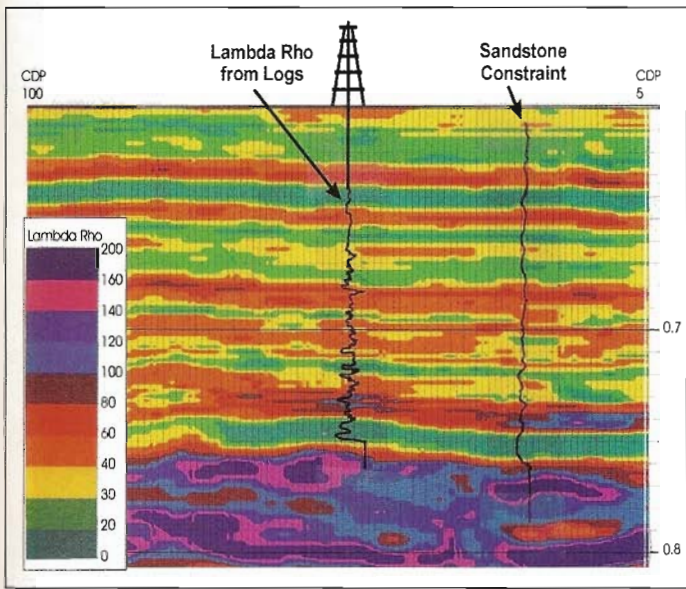


Figure 5a. Lambda Rho plot of the seismic line using a thick gas bearing sandstone scenario as the constraint

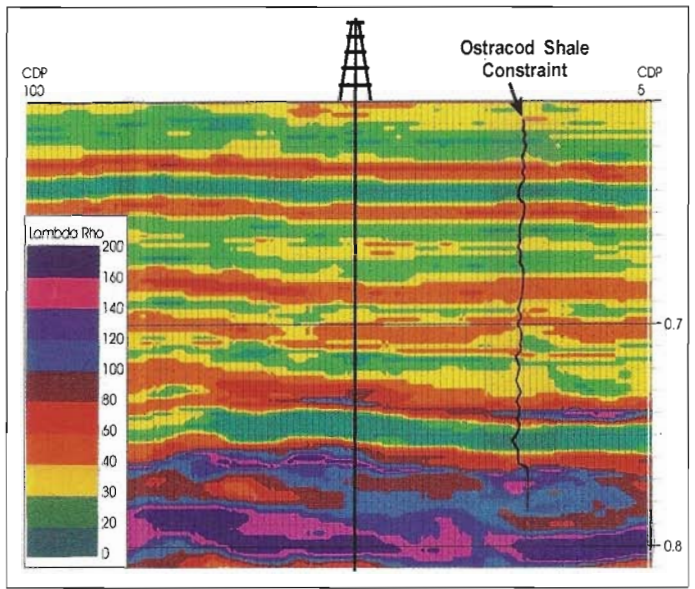


Figure 5b. Lambda Rho plot of the seismic line using a thin Ostracod shale scenario as the constraint

The well was drilled, and the results were somewhat unexpected: there existed an anomalously thick Ostracod Shale overlying a thinner sand unit in the zone of interest. The logs from the well are shown in figure 6. The sand is at 1077 to 1080.5m, and it is unclear on the neutron density and the resistivity curves whether

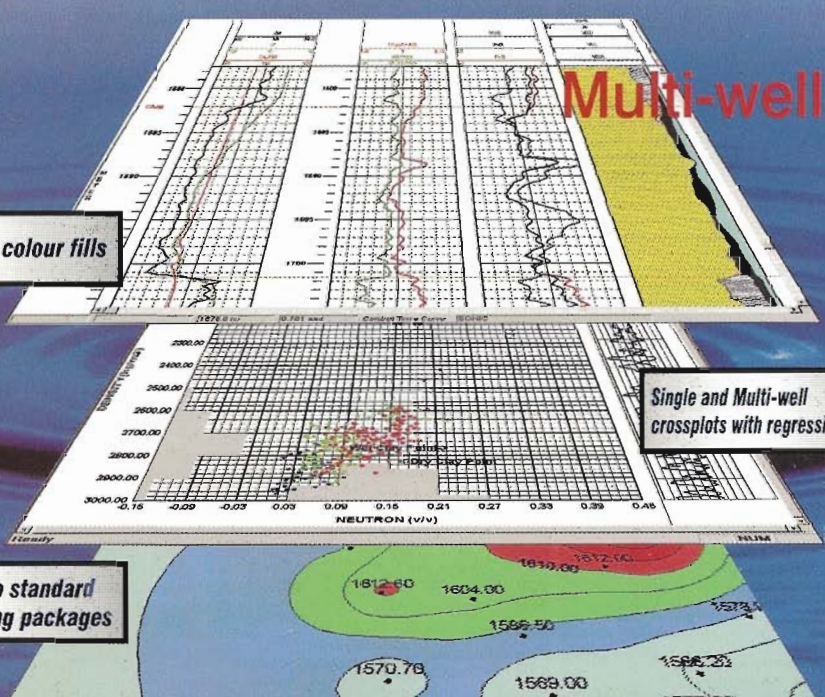
the zone is gas bearing or not. The ALHI method was performed using the full waveform data recorded. The ALHI crossplot is shown in figure 3. A cluster of samples with anomalously low SCRA values was circled and subsequently flagged beside the logs shown in figure 6. The gas flag appears beside the sand zone under

GMA
innovative software
with first class
support

Plot well logs and colour fills

Call Today
for your FREE
fully functional
evaluation copy!

Seamless export to standard
industry contouring packages



Single and Multi-well
crossplots with regression

MWLA

Multi-well Log Analysis

MWLA is a flexible Multi-well Log Analysis tool designed to handle both single well analysis and large reservoir studies. MWLA is designed with ease of use, intuitive detail and integration as essential qualities. MWLA encompasses such features as: the ability to scan multiple well logs and identify lithology using well log curves, perform interval statistics, create multi-well cross plots with regression analysis, and calculate porosity, water saturation and reserve summaries.

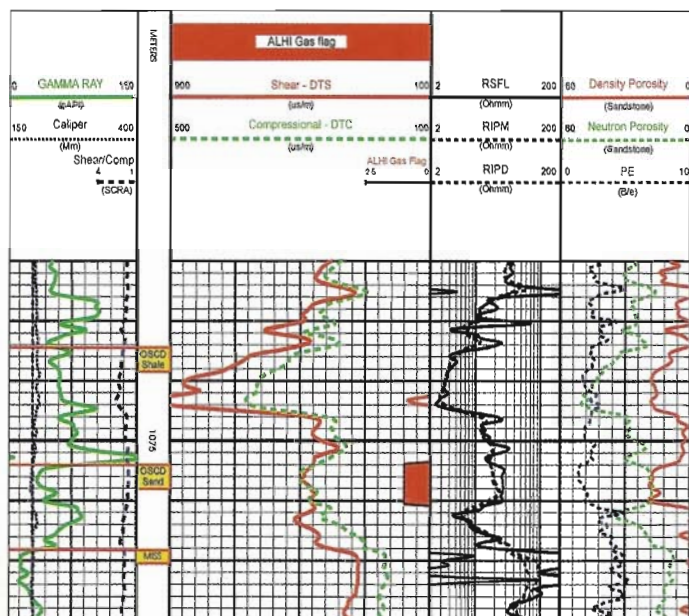


Figure 6. Open hole logs of Enchant well. Note the ALHI gas indication at the Ostracod Sand (OSCD)

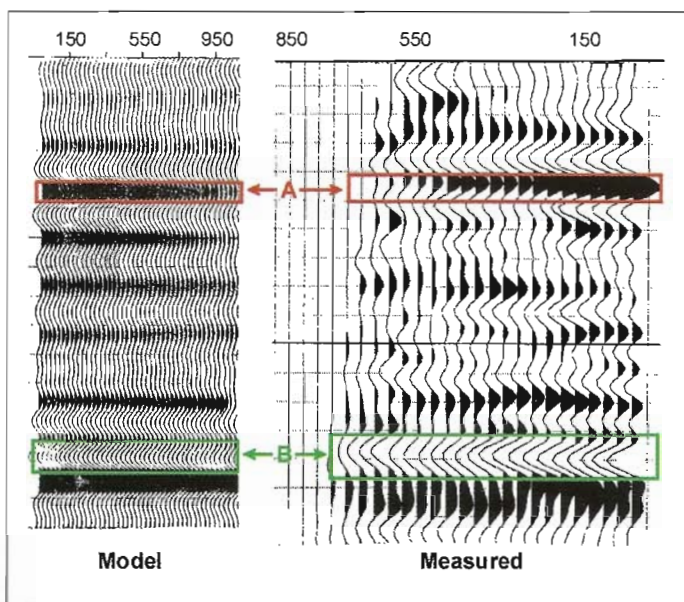


Figure 7. Modeled versus actual seismic gather. The zone of interest, "B", is enclosed within the green box and another cretaceous zone appropriate for comparing amplitude, "A", is in the red box. Note the slight decrease in amplitude with offset apparent at the zone of interest on both the synthetic and the real data

Committee Members

Publisher:	iDEA MACHiNE iNC.
Layout and Design:	iDEA MACHiNE iNC.
Chairman/Editor:	Michael Cheng, Dave Llewellyn
Advertising Manager:	Taras Dziuba

discussion. The well was cased and production tested with initial rates of 85,000 m³/d of gas.

The question remained as to whether or not the AVO inversion work was in error. Two things were done to check this aspect of the geophysical work: the first was to create a synthetic multi-offset model to compare to the final processed gathers that were input to the AVO analysis, and the second was to overlay the Lambda-rho curve calculated from the full waveform acoustic log on to the Lambda-rho inversion from the seismic. Figure 7 shows the comparison of synthetic versus actual seismic gathers. The AVO character at the zone of interest on these gathers is similar enough that we must conclude that the data conditioning was performed adequately. The Log derived Lambda-rho overlay is illustrated in figure 5a, and is a good match to the seismic lambda-rho estimate. The reason for this is: the anomalously thick Ostracod shale, together with the thinner gas sand form the basis for the seismic anomaly, and constitute an unexpected third possibility that was not modeled for. This result is an interesting illustration of the problem of non-uniqueness in seismic interpretation. The modeling and inversion work that had been performed prior to drilling the well had focussed on the simple question of gas sand versus Ostracod shale, and had never considered a third possibility that included unusual thicknesses of both. By integrating the techniques of AVO inversion and AVO modeling with measured multipole array acoustic data, ambiguities can be minimized.

Conclusions

The full waveform acoustic log is useful to exploration as a tool in formation evaluation, as well as a desirable element of data to be used in conjunction with AVO inversion work both prior to and after drilling exploration prospects. In the example illustrated here the full waveform data helped to identify a gas sand in the drilled well, and verified the validity of the AVO inversion performed prior to drilling the well. The full waveform acoustic log may play a role in the entire cycle of the AVO exploration paradigm.

Acknowledgements

We would like to thank Steve Dyer of Calahoo Petroleum, Yongyi Li and Jon Downton of Integra Geoservices inc., Ana Abad of Veritas DGC GeoServices, and John Parkin of Baker Atlas, for their assistance and encouragement in this project. ♦

Advertising inquiries should be directed to the Advertising Manager or the Publications Chairman care of the CWLS office.

Issue 4, December 3

Published by the Canadian Well Logging Society
1600, 734 - 7th Ave S.W., Calgary, Alberta T2P 3P5

Chairman's Remarks

At long last we have managed to get organized enough to publish another issue of the *in-site* newsletter. I would like to thank those individuals who have patiently guided me through this process, our authors and advertisers. It has definitely been difficult to attract articles for the newsletter and I must stress that we can only produce a quality publication if our members are committed to the process. There are four issues for publication next year as well as another "GEO-TRIAD" like convention in spring/summer 2000 so let's get thinking about those articles and papers.

We are also trying to keep up with our Members on the Move so please drop us a line to let us know where you are now.

David Llewellyn
Publication Co-Chair ♦

1998-99 Board of Directors



back row: Don, Reigh, Dave, Doug, Rob
front row: Carolyn, Glenn, Jim, Mike

Members on the Move

Members	Previous Location	New Location	City	Telephone
Jeff Levack	Tucker Wireline	Husky	Calgary	264-7040
Bob Park	AOG	Wiser	Calgary	237-9550
Reigh MacPherson	Wascana	Mobil	Calgary	260-7335
Rick Bernard	Talisman	Talisman	Aberdeen	001.441.224.733.059
Donna Bird	Pan-Canadian	Murphy	Calgary	290-3537
Craig Lamb	Lonach	GeoQuest	Calgary	509-4283
Nicole Donais	Vermillion	Suncor	Calgary	269-8100
Joe Halas	GeoGraphix	Applied Terra Vision	Calgary	218-8303

1998 C.W.L.S. Executive

Position	Name	Company	Business Number	Fax Number
President	Mr. Jim Prior	Computalog	298-3838	238-3880
Past President	Mr. Glenn Gray	BPB Wireline	234-9144	237-5480
Vice President	Mr. Reigh MacPherson	Mobil Canada	260-7335	260-7297
Treasurer	Mr. Rob Garth	Northstar Energy Corp.	213-7958	213-7999
Membership	Mr. Doug McGlashing	BPB Wireline Services	234-9144	237-5480
Chairperson Secretary	Ms. Carolyn Niemi	Accu Map a division of QC Data	270-1419	283-6250
Publication Chairperson	Mr. Michael Cheng	Canadian Petroleum Ltd.	234-6921	234-6498
Publication Co-Chairperson	Mr. Dave Llewellyn	Shell Canada Ltd.	691-3091	266-6248
Committee Chairperson	Mr. Don Cole	Baker Atlas	571-1000	n/a

Society News

On Tuesday, November 10th, at the Great Bash of 98, I had the privilege to present a cheque to the CWLS executive in the amount of \$73,750.00. Minus the \$4500.00 seed money, this cheque represents a profit of \$69,250.00 shared revenue from the Geo-Triad convention held in Calgary in June of 1998. Due to the huge success of the convention and profits generated, the CWLS, CSPG and CSEG will have additional revenues to propel them into the next millennium.

I would like to thank the CWLS executive in supporting my appointment in representing the society as a Co-Chairman for Geo-Triad '98 convention held in Calgary.

Almost three years ago the CWLS, CSPG and the CSEG decided to jointly hold a convention. This was the first time that the three societies would join to hold a convention.

Representatives of each society were selected, Jim Reimer, CSPG; Doug Uffen, CSEG; Monty Ravlich, Special Advisor and myself representing the CWLS.

Our first duties during our early meetings between the four of us was to select a theme and place of venue. A catchy theme was needed to get the memberships' attention and a venue was



needed to provide the facilities for several thousand attendees. With a combined membership of 6000 and an anticipated attendance of 3000 we selected the University of Calgary and Olympic Oval. The talks would be held on campus while the exhibitors would use the Olympic Oval. The theme was decided to be Rocks, Risks and Rewards. The first day of the three day convention had presentations solely on Rocks, then Risks and the final day focused on Rewards.

Just under 5200 people attended the convention and strong sponsorship support was received from all sectors of the petroleum industry.

By all measures, the Geo-Triad '98 convention was a resounding success. We exceeded our financial and participation targets while re-engineering the venue.

The credit for this remarkable effort goes to more than 200 volunteers on the 20 organizing sub-committees. On behalf of the general Co-Chairs and our respective societies, I thank them all for a job well done.

Winston Karel
Amoco Canada Petroleum Company Ltd.



G.H. LONGO

BUSINESS MACHINES

239 - 12 Avenue S.W.

269-6756

* SALES * SERVICE * SUPPLIES *
* LEASING * RENTALS *

NEW - REPOSSESSED
FULLY RE-CONDITIONED & GUARANTEED

MICROFICHE READERS - PRINTERS

PHOTOCOPIERS - FAX - DICTATION
PROJECTORS - PRINTERS, ETC.

«30»
YEARS

CANON - IBM SALES &
SERVICE SPECIALISTS

«30»
YEARS