General Geology

Geological Evaluation of Atomic Dielectric Resonance Surveys

Jim Ward Consulting

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Contents

1. Executive Summary

Between 2007 and 2010 Adrok Limited carried out Atomic Dielectric Resonance (ADR) surveys for Caithness Petroleum Limited in Morocco, Scotland and Oklahoma, USA. The results show that ADR technology has been successfully used to identify gas and oil bearing rocks in the subsurface, to determine the lithologies of these and adjacent rocks and to accurately measure their depths down to over 1800 metres.

ADR surveys were conducted at the sites of currently producing oil and gas wells, at abandoned wellsites both onshore and offshore and at undrilled prospects. This was the first large-scale use of ADR technology in oil and gas exploration.

Of the greatest interest in this project has been the success of ADR in accurately predicting hydrocarbons at two particular undrilled prospects: DNO-1 in the Rharb gas basin in northern Morocco and at the Butler Prospect-2 in Oklahoma, USA. Confirmation of the ADR predictions following the drilling of the two prospects proves ADR to be an important new technology for oil and gas exploration.

2. Introduction

This report is a summary of the geological evaluation by Jim Ward of Jim Ward Consulting of the ADR surveys carried out by Adrok Limited on behalf of Caithness Petroleum Limited from 2007 to 2010 in Morocco, Scotland and in the USA.

3. Objectives

The ADR surveys were made to identify subsurface hydrocarbon-bearing rock formations, to determine the lithologies of rocks in the subsurface and to accurately measure depths to particular geological horizons for the evaluation of oil and gas prospects; all to be achieved in advance of drilling.

Prior to the work described here, no comparable programme of pre-drilling prospect evaluation had been attempted in oil and gas exploration.

4. ADR Surveys

(i) Morocco

(a) Rharb Basin

ADR Technology

In 2007 Cabre Maroc Limited (a subsidiary of Caithness Petroleum) contracted Radar World Ltd (name now changed to Adrok Ltd) to carry out ADR surveys at certain gas well locations in the Cabre Maroc licence areas of the Rharb basin in Morocco.

The above project in Morocco was the first use of ADR technology for hydrocarbon exploration anywhere in the world. Cabre Maroc's principal objective in engaging Adrok to carry out ADR survey work in Morocco was to determine whether or not ADR could be used as a reliable direct hydrocarbon indicator in subsurface rock formations, and in particular, to identify significant gas accumulations and the depths at which they could be located at an undrilled prospect.

The Rharb basin was selected as a suitable trial area because of its relatively uncomplicated stratigraphy in which discrete gas accumulations are to be found in porous sandstones within thick marl sequences. The methodology was first to train the ADR equipment to identify by energy, frequency, phase, etc the electromagnetic radiation associated with specific downhole components such as gas, sand, etc, at existing wells (control wells). Then, where the same sets of electromagnetic data would be encountered in a test well the presence of the corresponding components could be inferred. This is called "typecasting".

In mid-2007 Adrok conducted a series of ADR surveys at pre-existing Cabre Maroc well locations in the Rharb basin. Surveys were also made in the vicinities of two exploration prospects which were to be drilled later in 2007. the well locations were as follows:-

Existing well:	BFD-1
	ZHA-1
	ZHA-5
	SAR-1
Undrilled prospects:	DNO-1

AHF-1

In the second half of 2007 Adrok generated virtual well profiles for the well locations where the ADR surveys had earlier been conducted. Cabre Maroc provided Adrok with limited amounts of data from existing wells so that the ADR system could be trained to recognise discrete electromagnetic responses associated with gas, water and sand at these control wells. Three frequencies were found by Adrok to be associated with gas, four with water and two with sand. When these frequencies occur in the test well then the corresponding downhole components are inferred to be present. A virtual well is then generated with the frequency data displayed in log format alongside previously computed electronic borehole records: depths, lithology, horizon thickness, dielectric constants, etc, the tail of the log contains a key to the layout of the parameters measured or derived from the ADR surveying and processing. The log is not drawn to scale. All the virtual wells that were generated by Adrok for Cabre Maroc/Caithness are included as appendices to the report by Jim Ward Consulting: "ADR Surveys Morocco 2007 to 2009".

ADR at pre-existing wells in the Rharb

At the start of the project Adrok set out to identify "significant" and "minor" gas shows in the subsurface, but the two terms were not very clearly defined. Petrophysically a "significant" gas show would be one that might have the potential to flow at surface; a "minor" gas show on the other hand would be non-productive. In their early analysis of the ADR data Adrok, through unfamiliarity with gas exploration, were treating some minor gas shows as significant causing over-reporting of "significant" gas zones in all the test wells. Up to twenty seven such zones were recorded at those wells, yet it was known that in the Rharb basin most of the successful wells had no more than two or three gas zones that could be developed commercially.

Initially Adrok had used mudlog gas data in the parameters for the mathematical modelling for virtual wells, unaware that such data were only approximately accurate. Better results were obtained using gas data derived from wireline logs. At this early stage, however, there were reasons for optimism: at BFD-1 the main gas zone had been identified. ADR had also differentiated between the upper sandy section and the lower marls in that well.

ADR at exploration prospects: DNO-1 and AHF-1

Two exploration prospects DNO-1 and AHF-1 were drilled in November 2007. Adrok had produced virtual well profiles in advance of drilling for each of the wells in October 2007. To guarantee the scientific integrity of the ADR work Adrok had received no data concerning these prospects prior to their being drilled.

DNO-1

The geological prognosis for this well made by Cabre Maroc had been based on the interpretation of seismic AVO signals (Equipoise Solutions Limited 2007). AVO anomalies are routinely used to identify potential gas accumulations in the Rharb basin. The Cabre Maroc geological prognosis had indicated potential gas sands within two sections:- at 495 and 520 metres (+/- 10 metres) and in deeper sands at 665, 690, 715 and 775 metres (+/- 25 metres).

On completion of the drilling, mudlogging and wireline logging of DNO-1, the prognosis that there would be two sections of the well containing gassy sands was shown to be basically correct.

The wireline logging analysis of DNO-1 showed two sections of the well containing significant or potentially commercial gas sands (as per prognosis): an upper gassy section, depths 458 to 506 metres, and a lower gassy section, depths 709 to 743 metres.

All the sands in these two sections were thin with only three sands exceeding one metre in thickness, ie 733.4 – 734.9, 735.2 – 736.5 and 738.9 – 740.3 metres in the lower section. In the upper section, five gassy sands were about a metre in thickness; one less than a metre. Two of the thicker sands: 457.9 – 458.8 metres and 484.2 – 485.2 metres had excellent porosities: 35% and 33% with good gas saturations of 47% and 33% respectively. These could certainly be considered as “significant” gas shows.

The virtual well of DNO-1 also showed the two gassy sections at similar depths to those identified by the wireline logging and as predicted by the Cabre Maroc prognosis.

DNO-1: Log Plot A and Log Plot B

The virtual well predictions of the depths to both significant and minor gas shows at DNO-1 have been tabulated against the corresponding data for gas shows determined by other methods. These data are shown in Log Plots A and B.

Log Plot A shows ten "significant" ADR gas zones highlighted with red dots. The wireline composite logs and computerised interpretation logs are shown to the left of the vertical well. Orange dots highlight the fourteen individual thin sands that had gas shows determined from the wireline interpretation log.

Log Plot A shows good agreement between the depths of the gas sands determined by well log analysis and the depths predicted from the ADR virtual well. A better and quite remarkable match between the two sets of gas zone depths can be achieved, however, if all the virtual gas depths are moved uphole by about 10 metres. This is shown in Log Plot B (otherwise similar to Log Plot A).

Log Plot B:- Virtual Well DNO-1 compared to the Wireline Interpretation Log with ADR depths reduced by 10 metres. (Enclosure 2).

From Plot B nine out of the ten red dots can now be seen to lie almost directly opposite similar groupings of the thirteen orange dots. The great similarities between the corresponding depths for the two sets of data is shown in the following table (Table 6 of "ADR Surveys Morocco 2007 to 2009").

Table 6:- DNO-1

Comparison of the depths for significant gas shows from wireline log analysis and ADR depths minus 10 metres.

Log Analysis metres	ADR depth minus-10 metres	ADR depth metres
484	484 - 486	494 – 496
505 - 506	504 – 506	514 – 516
640	637 - 639	647 – 649
709 – 710	710 – 712	720 – 722
730 – 740	737 – 739	747 – 749
742 – 743	740 – 742	740 – 752
756	755- 757	765 – 767

The remarkable match between the ADR minus 10 metres depths and the true depths for the gas shows at DNO-1 are the most significant results presented in this report, (Log Plot B and Table 6). It is improbable that the match between the two sets of data could have occurred by chance. The implication therefore has to be that the ADR analysis has been successful in identifying significant gas zones in DNO-1 but with a discrepancy of 10 metres.

The ten metre difference may be at least in part accounted for by the ADR virtual well location being some distance and at a higher ground elevation than the actual wellsite which at the time of the ADR survey was inaccessible due to farming. Other possible causes of the depth difference might be faulting and/or structural dip between the two locations.

AHF-1

AHF-1 was the second of the two exploration prospects drilled by Cabre Maroc in November 2007. The ADR survey for the well took place at the wellsite location. An ADR virtual well for AHF-1 was generated in October 2007 prior to the drilling of the well in November.

The wireline interpretation log for AHF-1 (depths 370 to 830 metres) shows there to be only one gas zone in the well at depths 536 to 539 metres comprised of two thin sands: 536 to 537.5 metres and 538 to 539 metres. The two sands are considered as separate gas accumulations for production purposes. There is an extremely thin (less than one metre thick) sand at 462 metres with a minor gas show. From the upper part of the log from 370 to 440 metres some very minor gas indications are possible in very thin sands in that section. The sands found in the marl section are generally thin, though some sands up to two metres in thickness are found from 568 to 596 metres but without gas shows.

The ADR virtual borehole record for AHF-1 produced an unrealistically large number of “significant” gas zones: some thirteen in all between depths 381 and 796 metres.

From the wireline log the lithologies which in the virtual well had been described as sands with “significant” gas were almost entirely marl with no shows.

The two gas bearing sands in the zone 536 to 539 metres were not recorded by the ADR though ADR “significant” gas zone at 526 to 528 metres is only eight metres away, an error of less than 2%. But that ADR recorded the presence of many spurious sands was disappointing. One possible explanation might be that the recorded depths may represent multiples of small gas zones possibly present in the higher sandy section of the actual well. This would be by analogy with the common occurrence of such phantom events in seismic records.

Disappointing results from AHF-1 may also have been caused by the use of mudlog data in the processing for the virtual well. However recently in the Rharb Basin commercial gas production has been obtained by Circle Oil from very thin stacked sands that were not seen on the standard wireline logs. Perhaps some such sands were being recorded by ADR at AHF-1.

<u>ADR Analysis by Algorithm</u>

In October 2007 Adrok developed a mathematical algorithm to generate a numerical parameter that could be related to the presence or absence of gas in the sands of the Rharb wells. The results of this Adrok work is collated in Appendix 11: Adrok Analysis by Algorithm.

ADR analysis by algorithm successfully predicted the depths of the main gas sands in SAR-1. The algorithm had been developed using only significant gas shows in ZHA-1 (803 to 809 metres and 931 to 934 metres) and ZHA-1 (1098 to 1103 metres). The algorithm gas predictions for SAR-1 were:- 1127 to 1131 metres and 1155 to 1157 metres. This compares well with the actual depths of gas sands in SAR-1:- 1123 to 1132 metres and 1153 to 1158 metres.

In January 2008 Adrok used the algorithm method to predict gas zones in DNO-1. Two depths were predicted:- 540 metres brt (below rotary table) and 749 metres brt. The latter depth was close to the actual depths of gas sands in the well.

In terms of petroleum geology, evaluation of the Adrok algorithm method is beyond the scope of this report but clearly these results are impressive..

Morocco – Fes area.

Following the ADR work in the Rharb, Adrok in 2007 carried out surveys in the Fes area. The area is geologically complex, being within the outer zone of the Rif nappe structures. Jurassic strata are thrust over the Miocene, frequently in repeated sequences. Virtual wells were generated at the sites of five old shallow wells none of which had been productive. No rock samples or cuttings from the wells were available for typecasting, but 52 core and cuttings samples from wells around 50 kilometres to the west were typecast. The rocks from this reference database were matched against each subsurface layer of the virtual well. Rocks with the highest correlation were shown on the left side of a rank matching table where horizon number, dielectric constant (DC) and horizon depth were calculated by triangulation of the ADR signals to each subsurface boundary using the WARR technique.

The virtual wells found some zones of low DC (values from 5 to 6), possibly indicating hydrocarbons. These data will be compared to the results obtained from Fes-1 recently drilled by Caithness when an ADR survey is carried out at that well.

Adrok in this area also generated a virtual seismic line some thirteen kilometres in length in which three of the old existing wells were used as reference points. The data recorded currently requires further reprocessing and interpretation.

4 (ii) <u>ADR Surveys in Scotland – Edinburgh area</u>

Following the ADR work by Adrok on behalf of Caithness Petroleum in Morocco, Caithness in 2009 contracted Adrok to conduct ADR surveys at three onshore sites in Midlothian, Scotland. Results from a survey at a well offshore Fife are also included.

The three onshore sites were:
(a) Cousland, near Dalkeith
(b) Joppa seashore, Portobello, near Edinburgh
(c) Newton House, near Dalkeith

The offshore site was at the well location of Firth of Forth-1 in the Firth of Forth, off the Fife coast.

The rocks at all the sites are Carboniferous in age ranging from the Coal Measures down into the Lower Carboniferous. A very wide range of well documented lithologies are present: sandstone, shale, limestone, dolomite, coal and volcanics.

The geology of these four areas has been published for many years so the ADR tests were not blind, but were nevertheless important in confirming the validity of the ADR technology.

In these surveys no cores or cuttings were available for typecasting. Adrok made use of the dielectric constant determined by ADR to find the depth to particular horizons, to identify gas and oil shows and lithologies. Results for Cousland were particularly impressive and are reported here in detail, being of most interest for hydrocarbon exploration. Results for the other locations are summarised.

4(ii) (a) Cousland

The ADR survey was carried out within the mapped area of the gas field which had been abandoned in the 1960's. Adrok had previously been provided by Jim Ward (JW) with the summary log and other data from the field obtained in the past from BP, including the stratigraphic positions of five gas-bearing sandstones and several oil bearing sandstones. The survey took place along a north-south traverse on the road leading south from Cousland village over the gas field area and about 50 to 100 metres from the position of the Cousland-1 gas well.

The Cousland gas field occupies an anticlinal structure on the eastern margins of the Midlothian coalfield, (figure 3). At surface is the Visean-aged Blackhall Limestone of the Lower Limestone Formation (LLGS). The LLGS is underlain by what is now called the Aberlady Formation in which the gas-bearing sandstones were found.

Stratigraphy of Cousland-1 well

Surface to about 113 metres:	Lower Limestone Formation (LLGS).
113 to 889 metres:	Aberlady Formation previously called the Oil Shale Group of the Calciferous Sandstone Series.

ADR Results

From surface to 113 metres the Lower Limestone Formation consists of two thick limestones separated by a 12 metre thick sandstone. The dielectric constants for the limestones in the section from surface to depth 28 metres were between 4.38 and 6.07. It is likely that these values can be attributed to weathering effects on the limestone over many millennia. Surface water draining through limestone would have caused dissolution cavities, leaving spaces filled with air thus reducing the dielectric constant (DC). Limestones below the 113 metres depth tended to be protected from this effect by impermeable shaly strata. Hence the deeper limestones have dielectric constants that fall within the range 7.81 to 8.9, more typical for this lithology. The sandstone from 56 to 68 metres had high DC values, between 12 and 13. These high values are attributed to the sandstone being saturated with ground water. At deeper levels DC values for sandstones decreased to around 10, which is interpreted here as indicating that the sandstones are partly wet.

Gas Sands

The depths of five gas sands determined by ADR were extremely accurate and the corresponding DCs were very low. Comparative data is shown below:-

Gas sand	1	2	3	4	5
BP Depth to top of sand (metres)	362.1	380	482	524	638
ADR Depth to top of sand (metres)	361.761	380.442	481.31	524.883	638.637
ADR DC	3.36	2.77	2.25	3.35	3.84

Oily Sands

Three "oily sands" were encountered at Cousland-1. The likelihood is that these sands had reasonably good oil shows though insufficient for production to the oil sands at the nearby D'Arcy field (3km to the SW) where some oil production was achieved in the past. Comparative data is given below:-

Oil sand	1	2	3
BP Depth to top of sand (approx metres)	448	457	693
ADR Depth to top of sand(metres)	451.968	457.111	694.126
ADR DC	4.05	4.09	5.31

DCs for lithologies interpreted as shales in the upper part of the ADR survey ie to depths about 164 metres were high, in the range 8.5 to 9.5 corresponding approximately to the section where the DCs of the sandstones were also high. This is interpreted as being due to high water saturation. At deeper levels the DCs of the shales were close to normal at 6 to 6.8. The shales having DCs between 5.2 and 5.95 at 245 to 342 metres, coincided with the descriptions of bituminous shales that contained thin oily sandstones at the Cousland-1 well.

Conclusion

At Cousland, Adrok had the benefit of data from Cousland-1 well. Nevertheless, the results of the ADR survey at Cousland were impressive. Depths to the gas sands and the oily sands were very accurate, comparable to the depths found by drilling. The determination of accurate depths to subsurface rock formations by DCs would, therefore, seem to be a very useful application for ADR technology.

At Cousland, ADR found the DCs of hydrocarbon gas-bearing sandstones to be significantly lower than those without gas: values being in the range 2.25 to 3.84. Oil-bearing sandstones also had reduced values for DCs (4.05 to 5.31). Both of these findings may have practical application in hydrocarbon exploration and production. For example, gas and oil-water contacts may be determinable by ADR. The technology may also be potentially useful for mapping the lateral extent of hydrocarbons in a sandstone reservoir, etc.

4(ii) (b) Joppa

Rocks belonging to the Coal Measures underlain by Namurian clastics outcrop with dips of 60 degrees down to the east at the Joppa seashore at Portobello near Edinburgh. One significant limestone: the Castlecary Limestone occurs at the base of this stratigraphic sequence. Adrok were unaware that due to the dip of the beds, the Castlecary Limestone would be found at twice the expected stratigraphic depth from surface. Nevertheless, ADR by means of the DC recorded limestone at the appropriate depth, confirming that accurate vertical measurements of lithology could be made within highly dipping strata.

4(ii) (c) Newton

The location of Newton House, Dalkeith is at the centre of the Midlothian coalfield syncline, near Edinburgh. Within the Coal Measure sequence ADR identified seven coals by their high dielectric constants, having values ranging from 17 to 24.

4(ii) (d) Firth of Forth

The well Firth of Forth-1 was drilled offshore the coast of Fife in 1990 through Lower Carboniferous strata overlain by ten metres of Tertiary rocks. The Tertiary rocks being soft and highly saturated with water had values of DC as high as 45.

Fourteen known coals in the upper section of the Carboniferous were all identified having DCs in the range 13 to 22.

A number of sandstones at depths between 1000 and 17 metres were recorded on the composite log as having oil shows. These were found to have DCs with reduced values of between 4.35 and 5.51 indicative of the presence of hydrocarbons.

4 (iii) <u>Surveys in Oklahoma, USA</u>

In 2010 Adrok ran ADR surveys at the Butler and Seward fields in northern Oklahoma. After the surveys were run two wells were drilled, one in each field. The pay zone in these fields is the Wilcox Sandstone.

(a) Butler Field

ADR surveys were run at the Butler-1 production well and at two undrilled prospects. The tests were blind, no well data being provided before the surveys.

The ADR virtual well for the Butler-1 well had twelve dielectric log hydrocarbon indications at depths between 5000 and 73000 feet (DC less than 6). There were nine wireline well log shows in the same interval. Raising the depths of the virtual shows, including that for the Wilcox Sandstone, by 50 to 70 feet gives reasonably good depth convergence between seven of the shows from the two data sets, the depth discrepancy then being about 1%.

The Butler-2 well was drilled in 2010 after the ADR survey. Dielectrics predicted hydrocarbons at 7008.5 to 7030.4 feet. Significant accumulations of gas were found at 7030 to 7080 feet and 7080 to 7106 feet. The 21.5 feet difference in depth to top Wilcox represents a divergence of some 0.3%. This provides further proof that ADR can predict the presence of hydrocarbons and at accurate depths.

(b) <u>Seward Field</u>

ADR surveys were run at the Klockner-1 production well and at two prospects: Klockner Prospect-1 and Klockner Site-3. Prospect-1 was drilled in 2010 after the ADR survey. The ADR results are currently being processed (August 2010).

5. Discussion

The results obtained by ADR technology in Morocco, Scotland and the USA can be summarised as follows:-

(i) The ADR virtual wells for DNO-1 (Rharb Basin, Morocco) and Butler-2 (Oklahoma) provide clear proof that the ADR technology can successfully predict the presence of hydrocarbons at accurate depths in the subsurface in advance of drilling.

(ii) A variety of lithologies from the Scottish sites including sandstones, shales, limestones, dolomite and coal were identified in the subsurface.

(iii) The pronounced effects of gas and oil on the dielectric constants of sandstones was demonstrated at Cousland and the effects of high water saturation in clastics and coals at Joppa, at Newton and in the Firth of Forth-1 well.

(iv) Accurate depth measurements to particular geological horizons were made at all the Scottish sites and at wellsites in the Rharb Basin (Morocco) and in Oklahoma (USA).

6. Conclusion

The information presented in this report confirms the value of ADR as a new technology for hydrocarbon exploration.

J Ward,
11 August 2010.