Paper ID: 2004898

Employing Petrophysical techniques for evaluation of Gas Hydrates --- a case history from Eastern offshore.

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Abstract:

Gas hydrates are solid substance composed of water and natural gas, the most common being methane. Other organic gases, which can form hydrates are ethane, propane and butane and inorganic gases: H_2S N_2, O_2, Cl_2 and CO_2. They have ice-like crystalline structures of a water lattice with cavities, which contain guest gases. They are held together by Vander Waal forces under low temperatures and moderate pressures conditions. The guest molecule is necessary to support the cavity. Hydrates can accommodate large volume of methane gas. One volume of a fully saturated methane hydrate can produce 150-180 volume of methane on dissociation at STP. Due to this large gas handling capacity, hydrates have gained importance as a future energy resource.

Direct evidence of gas hydrates can only be established by actual recovery of sub-surface samples. However, there are a number of methods such as analysis of seepage gas, BSR, insitu measurement of petrophysical properties, detection of cooling pattern on IR images etc. which can suggest the presence of gas hydrates.

Due to nature of pore filling fluids like gas hydrates, ice, formation water and gas in a gas hydrate bearing formation, subtle changes are observed in physical properties. Log measurement of physical properties such as electrical resistivity and acoustic impedance are considerably affected and these deviations can help in identification and evaluation of gas hydrate bearing sediments.

Wells from eastern offshore have been taken for gas hydrate identification on the basis of log motifs. A well from other field in which presence of gas hydrates have been proven is taken as a standard well. BSR has been well established in this well. Log motifs of the wells from eastern offshore around BSR are compared with those of the standard well. Logs in these wells follow similar trends as those of the standard well. Thus BSR in these wells can be established on the logs. Crossplots between total porosity and acoustic impedance can now be generated and departure of the trends above and below the BSR can be seen. This shows the presence of gas hydrates above the BSR and free gas below it. Thus identification of hydrates can be done on the basis of log trends. Estimation of the gas hydrate saturation can now be made using standard Archie's equation or NMR response. The results have corroborated gas hydrate findings in core samples.

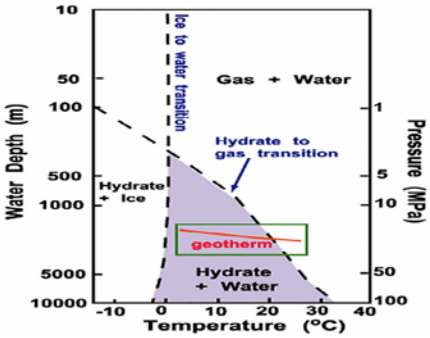
Introduction:

Gas hydrates are ice like crystalline substance consisting of water and gas. The water lattice forms a cage like structure, which is called clathrates. It is within these clathrates that the gas molecules get trapped. One of the most common gas that gets trapped is methane, although other gases such as ethane, propane, butane and other inorganic gases such as H2S, N2, O2, CO2 may also form hydrates. Gas hydrates have attracted worldwide attention due to their massive gas storage capacity. One volume of fully saturated methane hydrate gives 150-180 volume of gas at STP on dissociation.

History of hydrates dates back to 1811 when Humphrey Davy discovered hydrates by bubbling chlorine in cold fresh water. In Oil industry, Russians were the first to discover hydrates in Siberia in 1960.Later on hydrates were also recovered in Black Sea, Mackenzie Delta and other places. In Indian context occurrence of gas hydrates has been established in KG Offshore.

Occurrence of Natural Gas Hydrates:

The formation of gas hydrates is primarily controlled by three factors: Temperature, Pressure and Gas supply. Gas hydrate formation requires low temperature, high pressure and ample supply of gas. Natural gas hydrates can occur in a limited "Pressure – Temperature" zone called "Gas Hydrate Stability Zone" (GHSZ).



Phase diagram of Gas Hydrate

Fig.1. Typical environments for natural gas hydrate occurrence are the Arctic Permafrost areas and Continental margins.

Identification of Gas Hydrates:

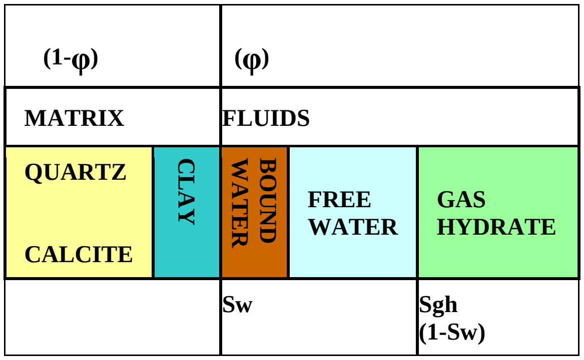
Although the presence of natural gas hydrates can only be established from the recovered subsurface samples, yet there are many techniques to identify gas hydrates. Some of the techniques that help us in identifying gas hydrates are analysis of seepage gas, identification of BSR, in-situ measurement of down hole petrophysical properties, measurement of salinity on core samples, detection of cooling pattern on IR images etc.

Bottom Simulating Reflector (BSR)

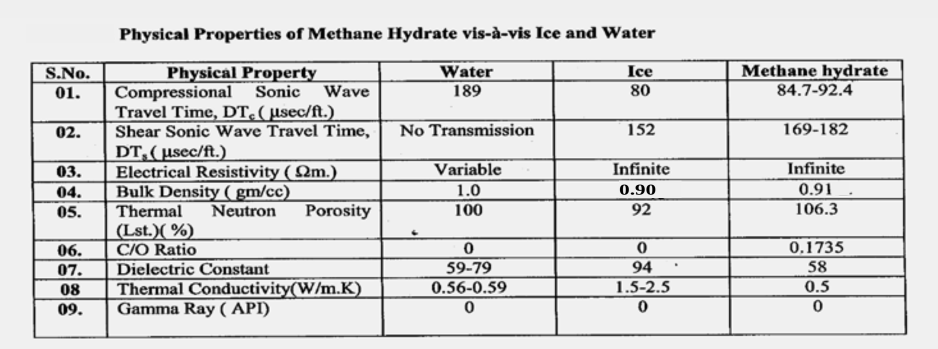
Gas hydrates are in deep oceanic regions and are generally recognized on the basis of bottom simulating reflectors (BSRs) on seismic sections. BSRs are strong reflections which run almost parallel to the sea floor and are believed to mark the base of gas hydrate stability zones. Free gas may be present, below BSR, which produces a large impedance contrast. There is an amplitude blanking above the BSR in gas hydrate bearing zone. The free gas that is below the BSRs can be huge and therefore potentially economically important. It can be shown that a correct estimate of the saturation, concentration and distribution of gas hydrate above the BSRs and free gas below the BSRs from logs and seismic sections is technically feasible.

Use of Well Logs for Gas Hydrate Identification:

The nature of pore filling fluids such as Gas hydrates; Ice, formation water and free gas dictate the physical properties of the gas hydrate bearing sediments. The sediments can be depicted as a solid part (matrix) and the porosity (φ), which is completely filled with fluid.



The responses of the logging tools such as neutron, density, sonic, NMR etc. is affected by the pore filling fluids and make hydrates identifiable on well logs.
A comparative table of log responses in various pore-filling fluids is given below:



Physical Properties of Methane Hydrate vis-à-vis Ice and Water

S.No.	Physical Property	Water	Ice	Methane hydrate
01.	Compressional Sonic Wave Travel Time, DT_c (µsec/ft.)	189	80	84.7-92.4
02.	Shear Sonic Wave Travel Time, DT_s (µsec/ft.)	No Transmission	152	169-182
03.	Electrical Resistivity (Ωm.)	Variable	Infinite	Infinite
04.	Bulk Density (gm/cc)	1.0	0.90	0.91
05.	Thermal Neutron Porosity (Lst.)(%)	100	92	106.3
06.	C/O Ratio	0	0	0.1735
07.	Dielectric Constant	59-79	94	58
08	Thermal Conductivity(W/m.K)	0.56-0.59	1.5-2.5	0.5
09.	Gamma Ray (API)	0	0	0

It is evident from above table that resistivity,density, dielectric constant and acoustic travel time are significantly affected. These log can help in identification of gas hydrates, although detailed analysis require complete log suite comprising of resistivity, sonic, bulk density, neutron, NMR, borehole imaging logs etc.

Qualitative Estimation of Gas Hydrates;

Gas hydrate saturation can be quantified using two approaches:

a) The standard Archie's equation and
b) The Density porosity-NMR porosity method

a) In Archie's method, the water saturation is calculated using the conventional Archie's equation

$Sw = [(a Rw) / (\phi^m Rt)]1/n$

Where Sw is water saturation,
a is Archie's constant
Rw is formation water resistivity
Φ is porosity
m is cementing constant
Rt is true resistivity of formation
and n is saturation exponent.

Assuming that total pore space is occupied by fluid containing water and gas hydrate, gas hydrate saturation is calculated as;

Sgh = 1-Sw, where Sgh is the gas hydrate saturation.

b) The Density porosity- NMR approach:

Both the Density and the NMR tool respond differently to water and gas hydrates. The density tool responds to total porosity occupied by both water and gas hydrates. On the other hand, NMR responds only to liquid water in pore space and not to solid gas hydrates, thus there is a departure in the porosity obtained from both the tool, which can be employed for gas hydrate detection.

Gas hydrate saturation can now be computed as follows;

$$Sgh_{(nmr)} = (DPHI - MRP) / (DPHI + \Delta^{*} MRP)$$

Where DPHI is porosity from density and MRP is magnetic resonance porosity.

And $\Delta = (\rho_w - \rho_h) / (\rho_{ma} - \rho_w)$

ρ stands for density and subscripts w, h and ma for water, hydrates and matrix respectively.
It is seen that relatively low porosity from NMR is obtained as compared to that from density porosity due to presence of gas hydrates.

Case History:

The above approaches to identify and evaluate gas hydrates has been employed in two wells X and Y from eastern offshore area. Log feature of the two wells have been comparedwith the logs recorded by Lamont Doherty Earth Observatory in Blake Ridge. The BSR is around 450m in this well.

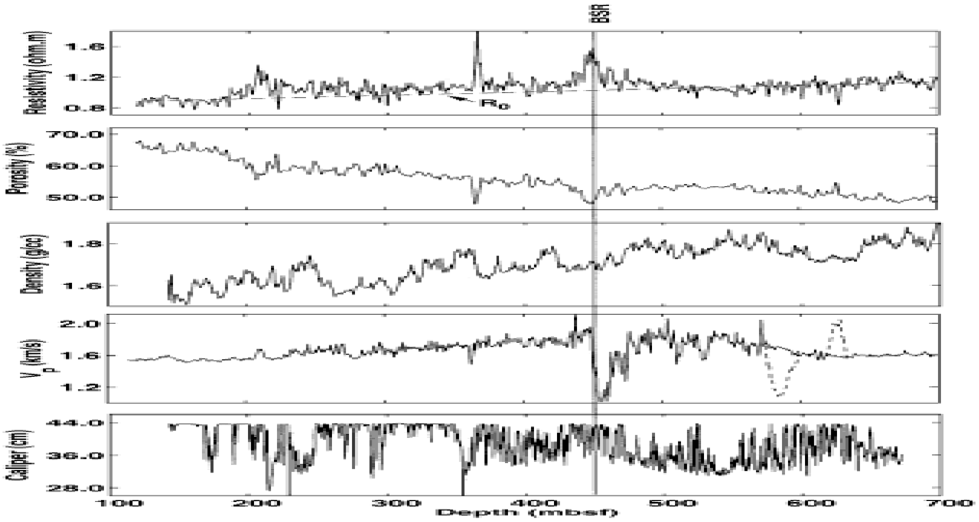


Fig. 2. showing various logs recorded by Lamont-Doherty Earth Observatory of Columbia University in Blake Ridge from various well. Note the BSR at 450m.

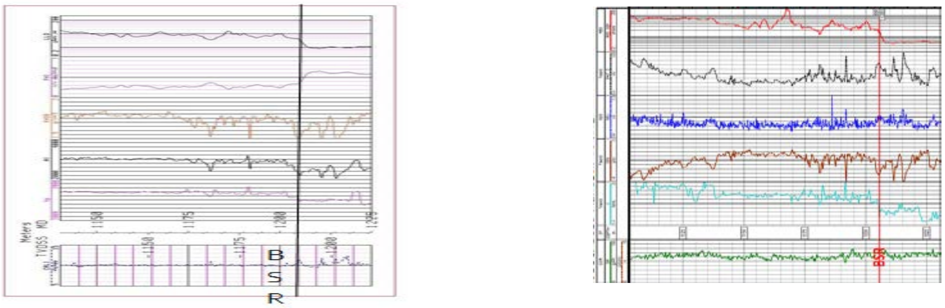


Fig.3. Log responses of well X (left) and wellY (right). BSR positioned on the basis of similar log response as those of Blake Ridge well.

Well X and Y show that the log response of Blake Ridge well and wells X and Y exhibit a similar trend. BSR can now be assigned in wells X and Y on the basis of the log motifs of Blake Ridge wells. Resistivity above BSR is high due to presence of gas hydrates and falls drastically below BSR. Above BSR water filled porosity values are low compared to normal compaction curve. Also P-wave velocity increases upto BSR and then falls abruptly. These features suggest the presence of different fluids above and below the BSR.

Identification of gas hydrates using Crossplot between Acoustic Impedance (AI) and Total porosity:

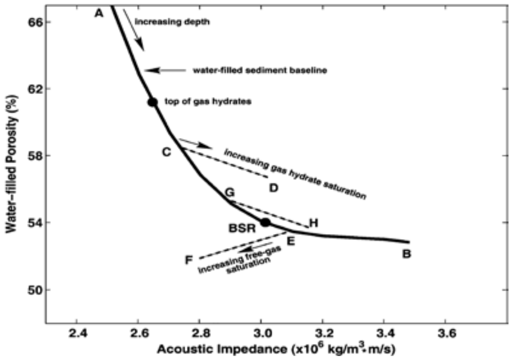


Fig. 4. Trends of gas hydrate and free gas points on AI-Porosity crossplot.

Fig.4 shows sediment under normal compaction in the absence of gas hydrate and free gas. The water filled baseline represents water-filled porosity versus acoustic impedance, a smooth baseline curve along which Φ decreases and I increases with increasing depth. The shift of the Φ–AI points above the baseline indicate the amount of hydrate present. In a free gas zone the shift of the Φ–AI points below the baseline indicates the amount of free gas present. Water-filled baseline separates the Φ–AI plane into regions containing gas hydrate (above the line) and those containing free gas (below the line).
Plots between Φ–AI for wells X and Y also shows similar kind of behavior establishing the presence of gas hydrates above BSR in these two wells.

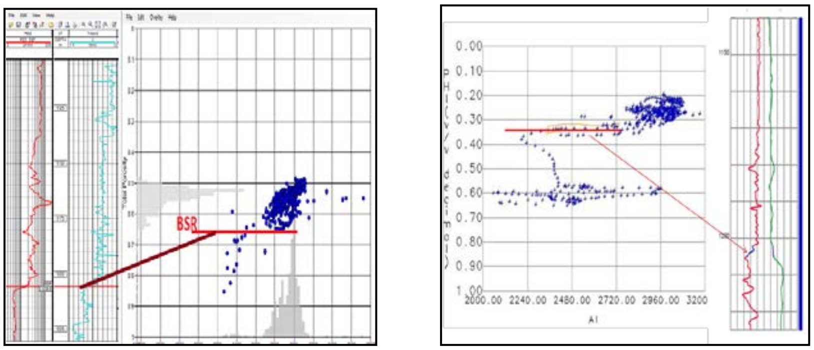


Fig. 5: cross plot between water filled porosity (Φ) and acoustic impedance (AI) showing gas hydrate above the BSR and free gas below in well X.(left) and well Y(right).

NMR Response in Gas Hydrate Wells.

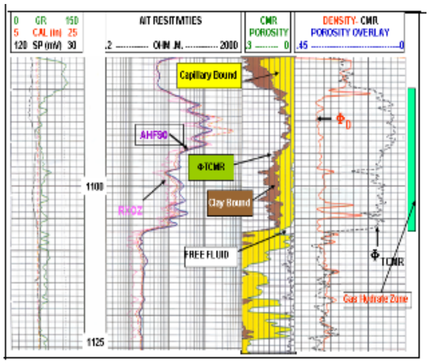


Fig.6.NMR response in a well from Mackenzie delta, Canada. This is a known gas hydrate bearing well.

Figure 6shows the NMR response in a known gas hydrate bearing well. The NMR porosity in gas hydrates is 5-10% and low free fluid porosity and high-density porosity of ~35% in hydrate bearing section. In water bearing section the NMR porosity and density porosity are almost equal. Free fluid porosity is high 10-30% in water bearing section. Similar response of NMR in well Y is seen.

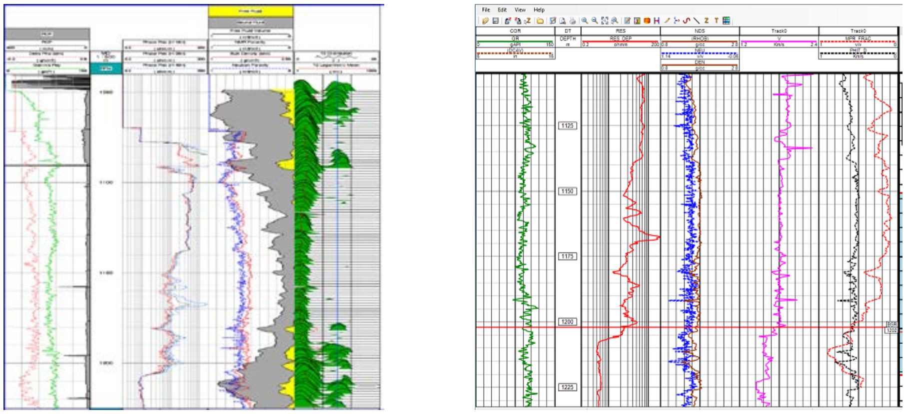


Fig. 7. NMR response in well Y (left). Gas hydrate interval is marked by low free fluid porosity and high free fluid porosity in water bearing section. Figure on right shows the difference between density porosity and NMR porosity in gas hydrate bearing section and overlaying in water bearing section of the same well. Gas hydrate bearing zone is marked by low NMR porosity and high-densityporosity.

Conclusion:

The present study establishes the importance of petrophysical techniques in identification and evaluation of gas hydrates. The combination of PHIT-AI crossplot and Densityporosity – NMR porosity method can predict the presence of gas hydrates with a high degree of confidence. The present case clearly brings out the following points in connection with gas hydrates studies:

1. Log motifs are affected by the presence of pore filling fluids. This gives the gas hydrate-bearing zone a distinct pattern on the logs.
2. BSR can also be recognized on the basis of logs.
3. AI- PHIT crossplot distinguishes the gas hydrate bearing points from non-gas bearing points.
4. NMR porosity-density porosity method establishes the presence and interval of gas hydrate bearing zone.

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Acknowledgement:

The authors are indebted to Shri Anil Sood, GGM-HOI-GEOPIC, Dehradun, India for providing the technical input and guidance for writing this paper. Thanks are due to Shri AK Tandon Head-INTEG, GEOPIC, Dehradun, India for providing all kind of support for this work. The authors are grateful to the concern geoscientist of this domain for providing necessary inputs. We thank ONGC management for allowing us to submit this paper in Geo-India 2015.

The views expressed in this paper are solely of the authors and do not necessarily reflect the view of ONGC.