Formation Evaluation in Complex Lithology using NMR data – A Case Study of Western Onshore Basin, India

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Summary

Nuclear Magnetic Resonance Imaging has emerged as the leading technological break-through which is providing difficult-to-interpret zones with the astounding results. Formation evaluation aims at finding out fluid saturations in varying geological formations making use of Resistivity, Porosities (Density, Neutron and Sonic), Clay indicators (GR, SP, Rhob, PhiN, Rt, DT, etc), and mineralogical identifiers (spectro metric tools). In spite of acquiring all the information, it is not possible to evaluate the accurate saturations in many cases and in some cases even the qualitative evaluation of saturations due to inherent ambiguities.

Unlike other conventional tools, the NMR measurements are largely based on the fluid and the pore space characteristics. This makes it possible to see the fluids and pores more vividly which are not seen on other conventional logs like Density, Neutron and Sonic. The coherence of conventional logs with NMR logs in normal clean sands and also the incoherence of conventional logs with NMR logs in shaly and detrital formations like trap wacke are discussed with Western onshore field examples where NMR has clear edge over conventional logging tools.

In the present case study Lower Sand - 1 (LS-1) of Ankleshwar field is examined, which is a highly complicated detrital formation reservoir, difficult to interpret and arrive at a conclusion. NMR data has made it possible to quantify the results and correlate petrophysical information provided by core analysis where conventional radioactive tools are not only silent but are misleading. These examples will suggest NMR as a unique solution provider and allow the neutron-density-sonic porosities to be redundant in such type of formations.

Introduction

LS1 Sand is a member of Cambay shale and about 50 wells have been drilled into this formation but very few wells have been completed for production. About 32 wells have been tested of which only 11 are producing. This unit (Fig. 1) consists of a coal band at the top (A), underlain by variegated clay/silt stone or trap wacke or trap conglomerate or weathered trap derivatives (B). Bottom part of the unit consists of fine grained silty sandstone(B*).

Cores cut in this unit do not show consistency throughout the field. One core shows conglomeritic, consisting of sub-angular, granules and pebbles of altered / weathered trap fragments. These weathered trap segments are cemented in clay (chlorite-ferrogeneous clayey) / silty clay matrix. Bottom part of core shows medium fine grained, moderately sorted light green sand stone.

X-ray Diffraction carried out on the cores from earlier wells show dominance of calcite with subordinate kaolinite and chlorite. Volcanic clastic sandstone, is greenish gray, hard, compact coarse to very coarse grained, sub rounded to rounded , moderately sorted. Trap fragments bounded by clay matrix. XRD studies have shown presence of calcite, montmorillonite, chlorite, kaolinite and traces of silica. It shows sandy clay stone in coarse sized scattered clusters of siderite and clay clasts. At places it is calcareous. The ground mass is ferrogeneous in nature. There are numerous small to big cavities formed either due to dissolution or unfilled amygdules.

Side wall cores from earlier wells describe the pay sand as trap conglomerate. Altered trap fragments are set in chlorite ferrogeneous clay matrix. Porosity is good and in the form of inter granular.

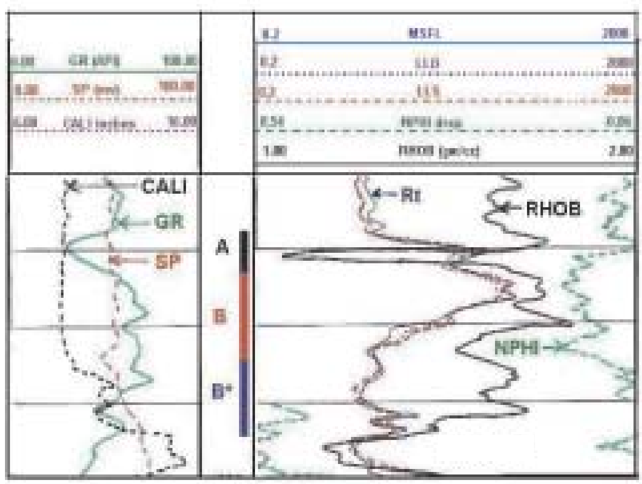

Fig. 1: Suite of Logs for lower sand-1(LS-1) of Cambay Shale in Ankleshwar field

It can be summarized that there is a quick change in lithology from place to place within LS-1 unit with mainly coal, trap wash/trap conglomerate, Variegated Clay associated with fine grained sand stone, silty clay stone of varying thickness is present all over the Ankleshwar field. Trap conglomerate and trap wash acting as the reservoir rock. Cavities formed due to dissolution or unfilled amygdule or inter granular porosity is acting as the pore space.

Present study

In the present study, detrital reservoir LS-1 has been studied to see the efficacy of NMR data. Typical log characteristics of LS-1 are Resistivity range varying from few

Ohm-M to few hundreds of Ohm-M. GR activity is high (50 to 90API), High Density (2.5 to 2.9gm/cc) with high Neutron porosity (50 to 70 PU). All the conventional GR, SP, DENSITY, NEUTRON data add to the complexity of log data interpretation(Fig. 1).

Typical deltaic sand (S2-1) has been taken for reference, where NMR confirms to the conventional log characters. This S2-1 sand is a member of Hazad Section. This middle Eocene S2-1 lower sand is a typical well granulated, medium to coarse grained with quantifiable amounts of shale. This well developed sand extends throughout the field. Log characteristics show clean sand with low GR activity well developed SP, 3 to 5 PU cross over between density and Neutron with presence of a mud-cake as is demarkated by Zone C in Fig. 2.

Conventional logs like Resistivity, GR, SP, Density, Neutron and Sonic provide almost complete information about the S2-1 sand member of Ankleshwar field.

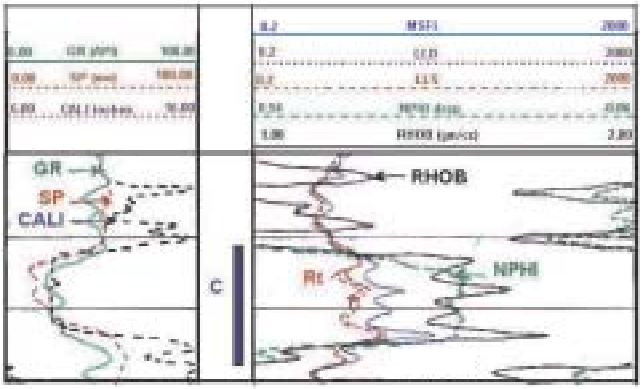

Fig. 2: Log Character for deltaic sand(S2-1) of Hazad Section

Ambiguity in LS1 log interpretation

It is very much evident from the logs that density neutron cannot provide any valuable information regarding LS-1 (Fig. 1). Especially neutron is high throughout the section and cannot throw any additional information about the geological formation. Log values of several wells are provided in Table 1.

As the complexity of mineralogical composition,

Table 1: Log values in LS-1 from several wells*Wells are producers.

Well No	GR API	SP mv	Resistivity ohm-M	Density g/cc	Neutron %
A1	40	7	30 – 100	1.3 – 1.55	60-63
A2	50	15	8 – 15	2.55 –2.79	60 – 66
A3	-	10	6 - 22	2.5 – 2.6	66 – 72
A4	-	12	15-50	2.8 – 2.9	61 – 63
A5		15	8 –12	2.4 – 2.65	51 –54
A6*	70	40	30 –150	2.55 –2.81	35-50
A7		15	3 –13	2.60 – 2.65	63 – 66
A8	30	15	5	2.6	25
A9*		10	6 – 50	2.52	69
A10*	18 – 50	-	25 – 400	2.50 –2.56	57 –66
A11*	45-70	10	6 –70	2.32 –2.63	60 - 66
A12*	40 – 70	-	5 - 150	2.4 – 2.8	60 – 70
A13*	50 – 70		8 - 80	2.4 – 2.7	52 - 70

matrix density, grain size (silt to conglomerates) fluid content, are not constant and keep changing due to the peculiarity of the depositional environment associated with detrital formations any attempt to quantify the water saturation would lead to erroneous results.

Looking at high values of density and neutron , arriving at porosity estimation with density neutron cross plot values is not possible. Approximation of porosity by taking only density into consideration also poses severe draw backs due to varying composition of matrix and cement. IRS, ONGC has conducted Core estimates from nearby wells which give average matrix density of 3 to 3.2g/cc, a = 1.013, m = 2.260 and n = 2.509. With these parameters zone marked as B in Fig. 1 gives a density porosity (uncorrected for shale) with an average of 30% and SW a value of 28%. By any estimate the derived porosity appears to be on higher side and SW values are erroneous. No guestimates can be made towards permeability or fluid movement with all these logs. Clay volume cannot be estimated and porosity correction is impossible. The sheer detrital environment introduces multiple ambiguities in lithology and hence mineral composition.

NMR: Nuclear Magnetic Resonance - Technological Break through

Nuclear Magnetic Resonance Logging has emerged as the most useful and productive technology in hydrocarbon assessment. The heartening thing is that it doesn't make use of the Radioactive Sources, though it deals with measuring of the hydrogen ion concentration. All Hydrogen nuclei in water, gas, and oil are single, spinning, electrically charged particles i.e. protons. These spinning protons create magnetic fields. When a strong external magnetic field (Large magnets of the tool) passes through the formation with fluids containing protons, these protons align along the polarizing field. This process called polarization increases exponentially in time with a time constant T1.

A magnetic pulse from a radio frequency antenna rotates, or tips, the aligned protons in to a plane perpendicular to the polarization field. The now tipped spinning protons in the fluid will precess around the polarization field produced by the permanent magnets in the tool.

The precessing protons acting like small magnets sweep out magnetic fields and this signal is measured. The time constant for this transverse relaxation process is called T2, the transverse decay time. The T2 and signal amplitude is dependant on number of protons (hydrogen ion), the pore size & space available. Matrix and cementation have very minimum effect on T2. The pore arrangement, grain size, interconnectivity of pores leading to permeability will determine T2. The pore size is directly proportional to the amplitude and time decay. The molecular hydrogen attached to clays and capillary (immovable) hydrogen effect die down within short T2 period where as free fluid hydrogen will have longer decay time. Density and Neutron derived porosities largely depend on the matrix, cementation, clay volume, fluid and minerals. It is possible to separate clay porosity, capillary porosity and free fluid porosity from the total porosity as a time component. Plate-3 shows T2 distribution in a silty formation. Plate 4 shows effects of silt and minerals on density and neutron porosity log values, the underlying fact are that it is not possible to separate the porosity, mineral and fluid contributions from each log where as NMR clearly distinguishes the various constituents.

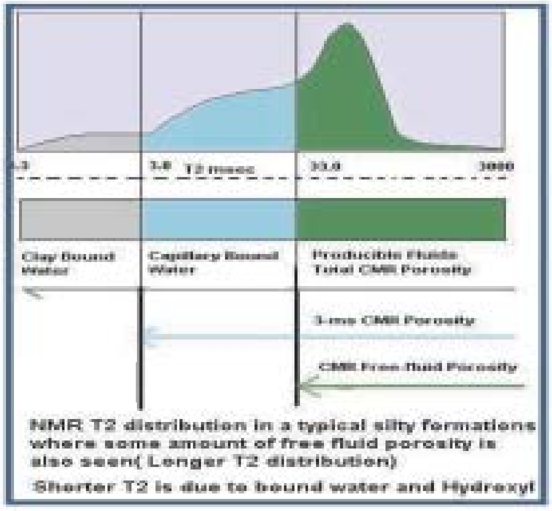

Fig. 3 : T2 distribution in Silty Formation

Discussion on NMR / Conventional log coherence and incoherence

The zone marked A (Fig. 1) is characterized by Low GR (30 API) , High Rt (50 ohm-M), Low Rho-b (1.9g/cc) and High N-phi (63 PU) and is categorized as coal layer. NMR log (Fig. 5) shows about 12% of total porosity with 5% small pore fluid porosity and 5% capillary bound fluid porosity with no free fluid porosity and no SDR and Timur coates permeability. T2 arrivals die out before 32ms cut off and NMR data is in agreement with Log signatures.

The zone marked B (Fig. 1) has High GR (70 API), High Resistivity (70 ohm-M), High Rho-b (2.65 g/cc) and Very high N-phi (65 PU). Phi-D and N-phi are clueless about the formation porosity and permeability where as NMR (Fig. 5) clearly delineates the reservoir portion of the formation. NMR log shows a total Porosity of 30% with clay bound porosity at 5%, Capillary porosity of 16% and producible fluid porosity of about 10%. T2 curves show the free fluid component extending up to 200 ms. SDR and Timur permeability are corroborating each other with a value of about 20 mD. It can be corroborated with core studies that Resistivity and density values are reflecting the grain size which is depicted by small pore and bound fluid porosity in NMR log. The absence of additional information from neutron cannot justify the Resistivity and density values making it difficult to characterize the reservoir. NMR input throws light on the character of reservoir.

The zone B* (Fig. 1) has all other log signatures are like that of zone B except for low Resistivity. This will lead to an interpretation of water bearing zone as this is in continuation with zone B (Zone B is hydrocarbon bearing). NMR log (Fig. 5) gives a total porosity of 35% with about all porosity representing capillary bound fluid porosity and little free fluid porosity leading to zero permeability. It amounts to a non

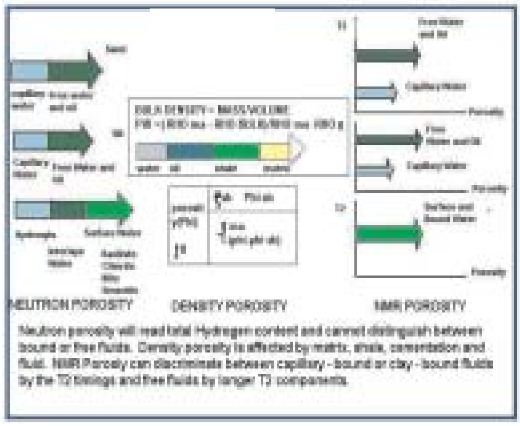

Fig. 4 : Effect of silt and minerals on density and neutron prosity log values.

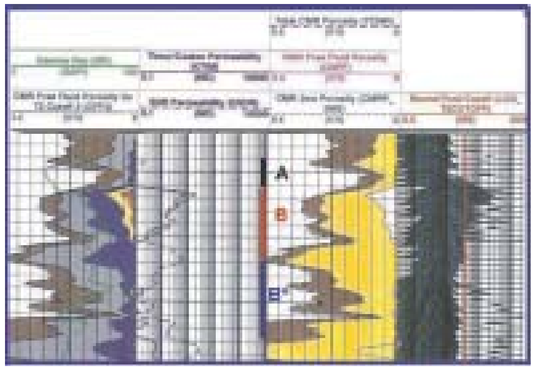

Fig. 5 : NMR logs with Timur Coates permeability

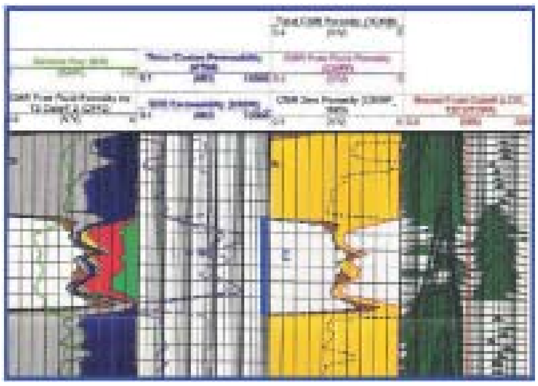

Fig. 6 : NMR logs with Timur Coates permeability

reservoir. The reduction in Resistivity and density can be easily attributed to grain and pore size after the addition of NMR input.

The zone C (Fig. 2) is characterized by low GR (30 API) Resistivity of 4 ohm-M, Rho-b of 2.35 g/cc and N-phi of 21 PU. Neutron Density derived cross plot (XP) porosity is about 18% and SW calculated with established parameters comes to 98%. NMR log (Fig. 6) gives a total porosity of 19% with 2% capillary pore porosity, 2% clay bound porosity and 15% free fluid porosity which is in perfect coherence with conventional log signatures.

Prior to acquisition of NMR information, qualitative as well as quantitative interpretation of LS-1 sand (Fig. 1) was restricted to opening of high resistive zones in this section and depend on actual production to estimate the pay zone thickness. NMR log has made it possible to identify the reservoir portion of the lithological unit and accordingly, the zone marked B in the plate-5 has been opened and giving a sustained production of clean oil. Table -2 presents quantitative results of formation evaluation with and without NMR input of LS-1 and S2-1 lithological units.

The value addition to formation evaluation is evident by the valuable information provided in the form of permeability, Clay bound volume and capillary bound volume of the detrital formations. The fast changing vertical sequence can be delineated and knowledge about the grain size and pore interconnectivity will help in designing the production completion for optimum exploitation. Several High Resistivity zones which are having Rt more than that of zone B which are shown in Table-1 have not flowed in spite of repeated perforations.

The coherence between core data and the NMR derived information regarding grain size, porosity and permeability is very high both in the case of LS-1 unit and S2-1 sand unit. Reservoir identification and characterization along with quantification of pay thickness and water saturation is the biggest contribution from NMR in case of Ankleshwar LS-1 detrital formation.

Table-3 provides a view of NMR value addition to formation evaluation which can be utilized for reservoir characterization.

Table - 2 Formation evaluation of Well No A-11* with Den/Neu Xp vs NMR porosityRw=0.1 Ohm-m, Rsh = 1.2 Ohm-M, a = 1.22, m=1.62, n=2

Zone/ formation	SP	GR API	Rt Ohm M	Rho-b gm/cc	Nphi PU	Phi-eff xp	Total NMR porosity	SW XP	SW NMR
A: coal	-	30	45	1.9	63	N.P	12	N.P	-
B: detrital	0	60	70	2.54	65	N.P	30	N.P	36
B*: detrital	10	68	6	2.35	66	N.P	35	N.P	100
C: sand	-25	23	3.5	2.38	21	18	20	96	100

Table 3: Value addition by NMR to formation evaluation in detrital sedimentsWell No A-11*Rw=0.1 Ohm-m, Rsh = 1.2 Ohm-M, a = 1.22, m=1.62, n=2

Zone/ formation	NMR porosity NMR permeability						SW% XPDen/ neu	SW % NMR	Grain size NMR	Grain size cor
	Total	Capillary	Clay Bound	Free fluid	K SDR	K Timur coates				
A: coal	12	5	5	0	0	0	N.P	-	fine	coal
B: detrital	30	15	5	10	20md	20md	N.P	36	Very coarse	conglomeritic
B*: detrital	35	2	33	0	10md	0	N.P	100	Fine	silty
C: sand	19	2	2	15	100md	>100md	96	100	medium	sand

Conclusions

The input of NMR data has simplified formation evaluation in detrital sediments. The porosity, grain size and permeability information can be used for optimizing the hydrocarbon production In fact NMR alone gives excellent delineation in complex LS1 reservoir where a hoard of conventional logs are silent on reservoir characters. The value addition of NMR in detrital reservoirs where the lithology is highly complicated and fast changing both laterally and vertically is showcased in this LS1 reservoir case study. The clear cut delineation with NMR and Resistivity information from a reservoir B to non reservoir B* in the same lithological unit makes NMR -Rt data superior to other conventional logs and probably a case for total value added substitute for other conventional logs.

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