

## Interpretation of Basal Clastic Reservoir Rock from Impedances Studies - a Case Study

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### Summary

Impedance of the reservoir rocks is inversely related to the porosity. In the set up, where the sand impedance is higher than the encasing shale, impedance of porous sands is closer to the shale on impedance axis and farthest for tight sands. Basal clastic sand unit of Panna formation in Heera of Mumbai offshore basin is one such example. Shale in the Basal clastic sand (BCS) unit is characterized by a unique value of impedance. Sands in the BCS unit have higher impedance, and their presence enhances the average impedance of the unit enabling delineation of sands on average impedance scale of the unit.

Certain percentage of Chlorite clay mineral and also higher impedance minerals are reported from core studies to be present in BCS unit. Very thin streaks of shale characterized by high density and NPHI are interpreted to be given by Chlorite as clay mineral on well logs within Panna formation. Presence of minor quantity of Chlorite mineral with sand does not influence the impedance of the reservoir significantly; whereas the presence of heavy minerals with sand enhances the impedance of reservoir rock.

Higher average impedance of the BCS unit above shale impedance (threshold) value is given by the presence of reservoir facies, irrespective of whether it is clean or shaly or mixed with heavy minerals and/or chlorite as clay mineral. Mapping of reservoir facies over the area from the average impedance above the said threshold value shows presence of reservoir rock all over the field and total impedance reveals its thickness qualitatively. This information in combination with the structural element helps to delineate the reservoir for exploration and exploitation.

### Introduction

Heera field in Mumbai offshore basin (Fig1) is a multi-layer reservoir. Bassein limestone of Middle-Upper Eocene age is the main producer through number of platforms. Considerable and sustained production rates from BCS unit of Panna formation of Lower Eocene age have drawn attention in recent past. Delineation of the Basal clastics sand unit of Panna formation is, therefore, required for its exploration and development. The working out a diagnostic seismic attribute to delineate the reservoir rocks in BCS unit has been an issue because of the following reasons.

Panna formation overlies the basement and is overlain by Bassein formation in case deposited otherwise by Mukta formation (Fig2). Upper part of Panna is dominantly shale whereas BCS unit in lower part of the formation is derivative of granite basement (Fig3). Panna thickness varies widely and is encountered in all the wells except on the basement paleo-high (Fig4). (Meckel, L.D. Jr., and Nath, A. K., 1977 & Neidell, N.S. and Poggiagliolmi, E., 1977)

Second, Core studies carried out over BCS units in three of the wells shows the Kaolinite and Chlorite as clay minerals and heavy minerals, viz. Siderite, Pyrite and Hematite etc. mixed with the reservoir rock. Very thin streaks of shale

having Chlorite as clay mineral characterized by high density and NPHI have been interpreted on logs within BCS interval (Boyer, S., Mari, J.-L., 1997).

Third, As the BCS unit top is not a correlative event on seismic data, the suitable and accurate window of BCS unit for deriving attribute has been an issue. Because of all the above, delineating of Panna sands through various attributes has not been successful.

Systematic study of well logs of all the wells over Panna formation shows that the reservoir rock of BCS unit either pure or shaly or/and mixed with heavy minerals is of higher impedance than the shale, and therefore average impedance above threshold taken over the BCS unit is a reliable diagnostic parameter to ascertain the presence of the reservoir rock. Total impedance over the BCS unit gives a qualitative measure of reservoir thickness. Seismic data inversion is carried out to help interpret reservoir rock through impedance. A mathematical twt surface corresponding to the top of BCS unit is worked out for a desirable window required for impedance attributes.

### Theory and/or Method

Shale in Panna can be characterized by certain velocity and density which is observed to have considerably lesser velocity and higher density than sand. Shale impedance is worked out to be lesser than that for sands. Porous sand is closer to the shale on impedance axis and farthest for tight sands. Some percentage of heavy minerals and Chlorite clay are reported in core studies to be mixed with the sands. Following understanding helps in interpreting reservoir rocks in terms of the impedance.

- Shale in BCS unit can be characterized by 120 us/ft velocity and 2.45-2.5 g/cc of density (Fig5a) and therefore a definite number of impedance ( $6200 \text{ m/s} \cdot \text{g/cc}$ ). Sands are observed to have considerably higher velocity and lower density ( $<100 \text{ us/ft}$  and  $>2.25 \text{ g/cc}$ ) than the encasing shale, resulting in higher impedance for sands than shale (Fig5b). Shale present in sand separates the NPHI-RHOB curve on their normal scale of display depending upon its quantity.
- Minor fraction of shale present in sand brings the velocity down and density up in proportion to its quantity, and in the process the impedance down (Fig5b). Impedance though still remains higher than that of the shale.
- Very thin streaks of shale having Chlorite as clay mineral characterized by density of 2.7 and NPHI of 0.45, sonic transit time of 100 us/ft on well logs have been interpreted within the BCS interval (Fig6). Presence of Chlorite clay in the sand gives more NPHI-RHOB separation than the same quantity of other characteristic shale in the unit. Based on the separation combined with interpretation of Gamma and sonic logs, a minor proportion of Chlorite mineral is interpreted to be present in the reservoir rock.

- Minor fraction of Chlorite clay present in sand doesn't affect the velocity appreciably, but brings density up, and therefore not affecting impedance of the reservoir rock significantly.
- Pore space in reservoir rock is not much affected by the presence of minor fraction of heavy minerals, but increase in density enhances the separation of NPHI-RHOB logs on their conventional display scale. Intervals showing lesser transit time on sonic log (higher velocities) combined with separation of NPHI-RHOB logs may be interpreted as reservoir rock (Fig6). Degree of separation of NPHI-RHOB and higher sonic velocity decide the amount of heavy minerals present.
- Presence of particles of heavy minerals like siderites (density 3.91g/cc and velocity 143.7 us/m) in sand increases the density and velocity, and therefore, the impedance of rock (Fig6).
- High value of Gamma at places is interpreted to be the reservoir rock from amount of separation of NPHI-RHOB logs and reading on resistivity logs and support from higher velocity on sonic log.
- No much tight sands are noticed on the well logs in the BCS interval. Higher average impedance over the interval is therefore interpreted as good reservoir rock mixed with heavy minerals.

Shale Impedance is worked out to be lesser than in sands. Minor fraction of shale present in sand brings velocity down, density up in proportion to its quantity and therefore the impedance down; but impedance still remains higher than the shale. Presence of heavy minerals increases the impedance of the reservoir rock, and therefore separation between reservoir rock and shale on the impedance scale. Presence of Chlorite as clay mineral does not significantly affect the impedance of the reservoir rock, and therefore the separation between reservoir rock and shale on the impedance scale. Based on the above understanding, Average Impedance higher than the shale over the interval is thought to be parameter diagnostic to interpret reservoir rock. This has led to carry out model based seismic inversion for impedance.

PSTM Seismic data processed for zero phase is available to carry out the seismic inversion. Time depth relationship derived through well seismic tie is used to convert the impedance in depth to impedance in time domain. 3D Model in time domain is generated interpolating impedance logs derived from wells having sonic and density logs. Horizons interpreted over the conventional amplitude seismic data in time have provided time structure to impedance model. The model is one of the inputs used for inversion of seismic data. The wavelet is extracted at a number of well locations to give best possible synthetic seismic and field seismic correlation coefficient. The composite wavelet consisting of derived wavelets is used as other input for inversion. QC was made for best selection of parameters before carrying out the inversion on PSTM seismic data. The output of seismic inversion the impedance volume in time domain was subjected to the extraction of total and average impedance over BCS unit.

As the BCS unit top is not a correlatable seismic event, the suitable and accurate window of BCS unit for deriving attribute has been the issue. A mathematical twt surface was successfully worked out corresponding to the top of BCS unit in the following manner.

- Inversion brought out clear definition of basement top as basement impedance is substantially higher than the overlying sediments. Basement horizon interpreted on trough on conventional amplitude seismic is fine tuned on the inverted volume from impedance contrast (Fig7 & 8).
- Around forty wells distributed over the area have sonic logs recorded covering interval from BCS unit top to basement. Average velocity from BCS unit top to basement is calculated for these wells and used for converting the above depth interval into twt time. Twt derived at forty well points is gridded to get the twt thickness of the said interval in the area.
- The twt thickness grid is subtracted from fine tuned basement horizon to get the time mathematical surface corresponding to the top of BCS unit (Fig7 & 8).

**Average impedance map over BCS Unit** as window is generated from impedances volume after subtracting the threshold shale impedance (6200m/s\*g/cc). As discussed, higher average impedance values come from the presence of lithology other than shale i.e. sands/ shaly sand/ sands mixed with high density minerals. Outcome is the impedance distribution in between the wells and in the area where wells are not there. It is overlain by the same attribute generated from the wells having sonic and density as the QC check.

**Total impedance over the BCS unit** as window is generated from the impedance volume after subtracting the shale impedance (6200m/s\*g/cc). Higher values are indicative of contribution coming from thicker reservoir facies. The map is overlain by the structure map at BCS unit top.

#### Conclusions

- Inversion clearly brought out the basement top on impedance volume which in turn helped to work out a mathematical twt surface corresponding to the top of BCS unit. Average and total impedance attributes are derived over the of BCS unit.
- Total Impedance map over the BCS unit as the window brings out the distribution of reservoir rock vis-à-vis its thickness.

#### References

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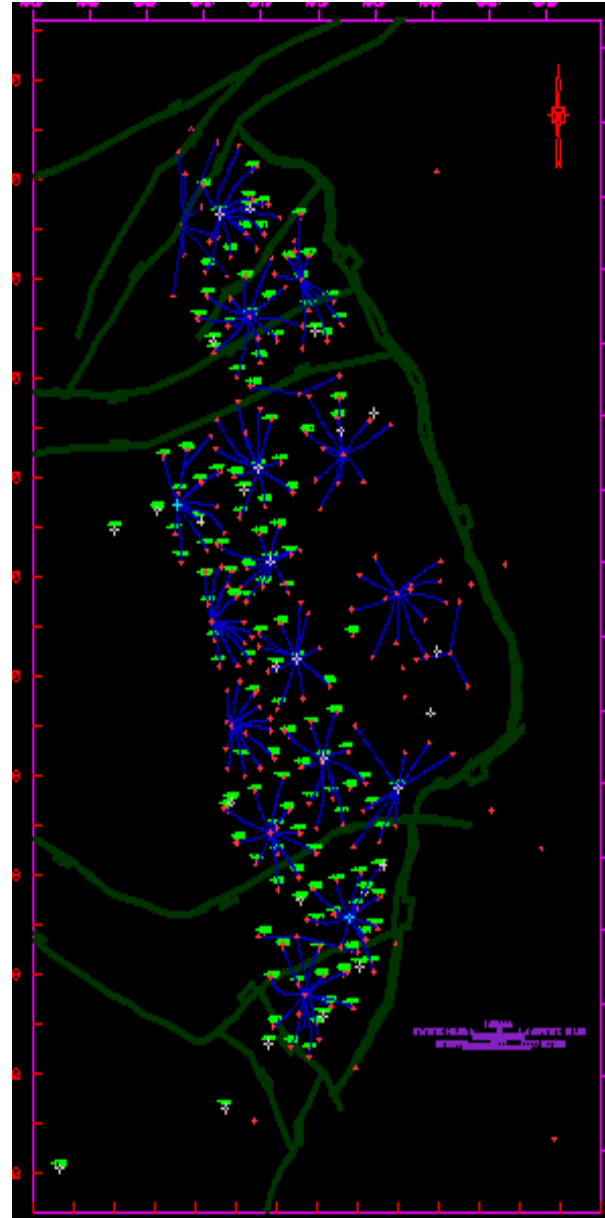


Fig 1 Well location map of Heera field. Wells having DT are shown in white color

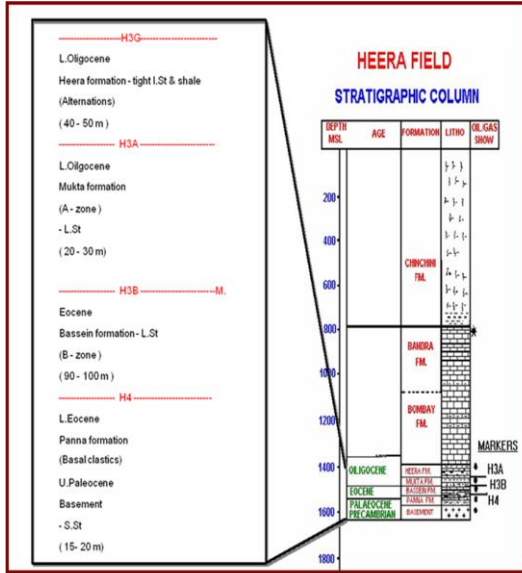


Figure 2: Generalised stratigraphic column of oil bearing zones of Heera Field

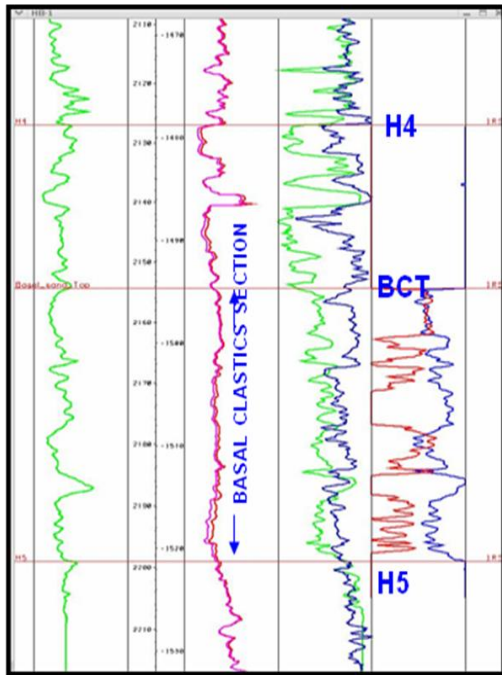


Fig 3 TYPE SECTION FOR BASAL CLASTICS

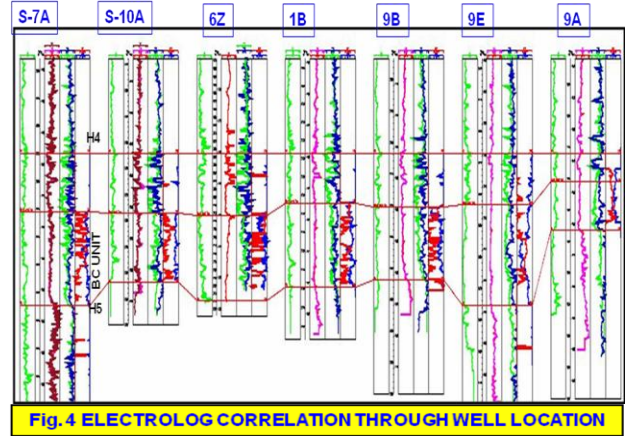


Fig. 4 ELECTROLOG CORRELATION THROUGH WELL LOCATION

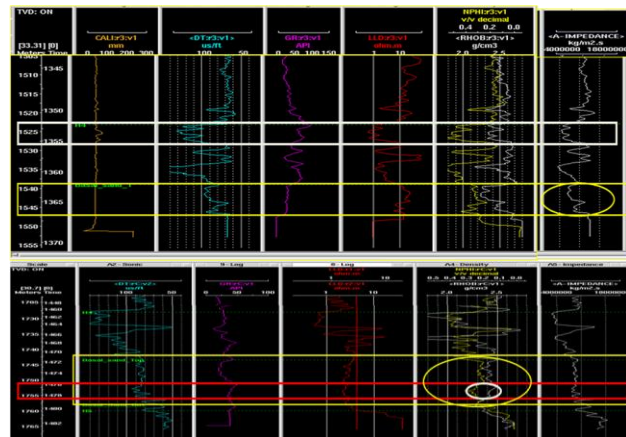
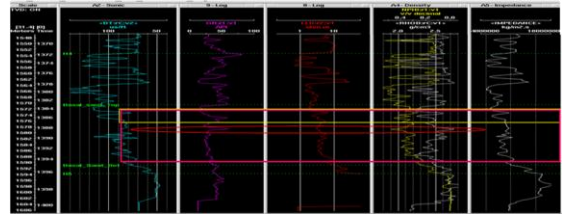
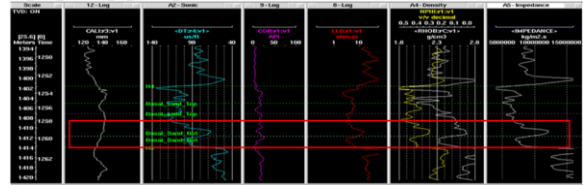


Fig 5 Reservoir rock and shale is interpreted from the log suite. Shale have higher density and lesser velocity than sand resulting into lesser impedance (a): Well- 6- 8. Small fraction of shale separates NPHI-RHOB, brings density up, velocity and impedance down (b): Well-D-E

interpreted to be shale Interpreted to be reservoir rock



9-B



A-H

Fig 6 Small streak interpreted to be Chlorite clay mineral is characterized by high NPHI, RHOB and transit type comparable to the sand. Minor fraction of Chlorite and/or heavy minerals mixed with sand separates NPHI-RHOB log. Interval is interpreted as sand mixed with chlorite and/or heavy minerals has high impedance than shale.

Small streak of Chlorite clay  
Interval interpreted to be reservoir rock      Perforated interval

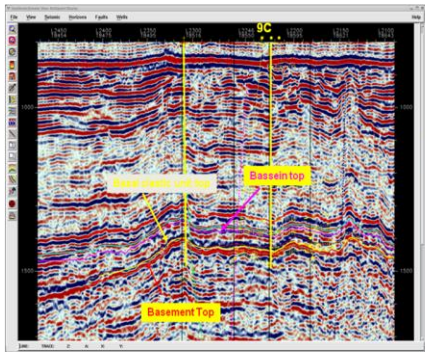
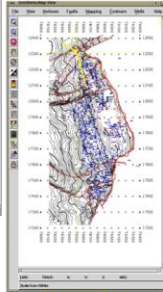


Figure 7 RC line connecting wells 6C, 9C and 7C



Basemap