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

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Abstract

Considerable and sustained production rates from Basal Clastic Sand (BCS) unit of Panna formation of lower Eocene age of Heera field have drawn attention in recent past, despite the sand unit being interpreted to be thin and not of good quality. Study has been taken up to understand whether sands can be delineated with the integration of seismic along with other geoscientific inputs. None of the attributes from conventional seismic volume are found to be diagnostic to delineate the reservoir rock in the unit. Shale in the Basal Clastic Sand (BCS) unit is characterized by a unique value of acoustic impedance. Sands in the unit have higher impedance and their presence enhances the average impedance of the unit enabling their detection/delineation.

Core studies of BCS unit show the presence of clay minerals viz. Kaolinite and Chlorite, heavy minerals viz. Siderite, Pyrite and Hematite etc. Very thin streaks of shale, characterized by high density and NPHI, are interpreted to be Chlorite on well logs. Presence of minor quantity of Chlorite within the reservoir does not influence the impedance; whereas the presence of heavy minerals enhances the impedance of reservoir rock significantly.

Average impedance of the BCS unit is higher in the presence of reservoir rock as compared to the average impedance of the characteristic shale, irrespective of the reservoir being clean, shaly or mixed with heavy minerals and/or chlorite as clay mineral. The difference between the total impedance (average impedance multiplied by the Two Way Time thickness of the unit) of the BCS unit and the total shale impedance (when sand is considered to be absent) is indicative of presence of reservoir. Higher differential values are interpreted as indicative of larger reservoir rock thickness. Reservoir distribution in combination with the structural element helps in the exploration and development of fields.

Objective of the Study and Difficulties Encountered

Hydrocarbons occur at multiple levels in the Heera field of Western Offshore Basin (Fig.1). Bassein limestone of Middle-Upper Eocene age is the main producer through a 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 sands in BCS unit of Panna formation is, therefore, required for its exploration and development. Working out a diagnostic attribute from seismic amplitude volume to delineate the reservoir rocks in BCS unit has always been an issue because of the following reasons:

- Panna Formation overlies the basement and is overlain by Bassein Formation. At places where Bassein Fm. is absent, Panna Fm. is directly overlain by the younger Mukta Fm. (Fig.2). Mukta and Bassein formations have different values of acoustic impedance.
- Upper part of Panna is dominantly shale having limestone streaks, whereas BCS unit which is derived from granitic basement forms the lower part (Fig.3).
- Panna is encountered in all the wells except those on the paleo-highs and its thickness varies widely.
- Core studies carried out over BCS unit in three wells show Kaolinite and Chlorite (Clay minerals) and Siderite, Pyrite and Hematite etc. (Heavy minerals) are present within the BCS unit. Thin streaks of shale having Chlorite are characterized by high density and high NPHI have been interpreted on logs within the BCS unit.

- BCS unit top is not a co-relatable event on seismic data, thus a suitable and accurate window for deriving attributes over the BCS unit has been an issue.

Fig.1 Well location map of Heera field.
Observations and Methodology

Following understanding helps in interpreting reservoir rocks in terms of the acoustic impedance.

Shale in BCS unit can be characterized by 120 µs/ft sonic transit-time and density of 2.45-2.5 g/cc (Fig.4a) and therefore a definite number of impedance value (6200 m/s*g/cc). Sand is observed to have considerably higher velocity and lower density (<100µs/ft sonic transit-time and density >2.25g/cc) than the encasing shale, resulting in higher impedance for sands than shale. Porous sands are plotted closer to the shale on impedance axis whereas tight sands are the farthest.

- Overlap of NPHI-RHOB log curves is interpreted as sand on their standard scale of display. Presence of shale in sands separates the NPHI-RHOB curves depending upon its percentage. Increasing shaliness decreases the velocity and increases the density resulting in the decrease of impedance in proportion to shaliness (Fig.4b). Impedance of shaly sands is therefore intermediate between clean sand and pure shale.

- Thin streaks of shale having Chlorite clay mineral characterized by density of 2.7 gm/cc and NPHI of 0.45, sonic transit-time of 100 µs/ft on well logs have been interpreted within the BCS interval (Fig.5). Presence of Chlorite in the sand gives more NPHI-RHOB logs separation than the same quantity of characteristic shale.

Fig. 2: Generalised stratigraphic column of Heera Field.

Fig. 3: Type section for Panna Formation.

Fig. 4: (a) Shales have higher density and lesser velocity than sand resulting into lesser impedance (Well-6-8). (b) Small fraction of shale separates NPHI-RHOB, brings density up, velocity and impedance down (Well-D-E)
in the unit. Based on the NPHI-RHOB logs separation combined with the interpretation of gamma and sonic logs, a minor proportion of Chlorite is interpreted to be present in the reservoir rock at places.

- Minor fraction of Chlorite clay present in sand doesn’t affect the velocity appreciably, but brings density up, without affecting impedance of the reservoir rock significantly.

- Heavy minerals like siderites have high matrix density 3.91g/cc and velocity 44µs/ft yielding high acoustic impedance.

- Presence of a fraction of heavy minerals does not affect pore space in reservoir rock, but increases the rock density thereby enhancing the separation of NPHI-RHOB logs. Thus the intervals showing separation of NPHI-RHOB logs caused by high density minerals, combined with lesser transit-time on sonic log (higher velocities) are interpreted as reservoir rock having significant amount of heavy mineral (Fig.6). Degree of separation of NPHI-RHOB logs and higher sonic velocity determine the amount of heavy minerals present. The presence of particles of heavy minerals in sand therefore increases the impedance of the reservoir rock (Fig.6).

- At places, some intervals despite having high value of Gamma log (Due to the presence of Orthoclase feldspar) are interpreted to be reservoir rock considering NPHI-RHOB logs, resistivity log and higher velocity on sonic log.

- Generally, tight sands are not noticeably present in the BCS unit. Higher average impedance over the interval is therefore interpreted as good reservoir rock having heavy minerals.

Based on the above understanding, the average impedance higher than the shale over the BCS interval is thought to be the parameter diagnostic to interpret reservoir rock. This forms the basis for carrying out seismic inversion to delineate reservoir rocks in the unit.

3D PSTM seismic data is one of the inputs for the seismic inversion. Other input viz. 3D impedance model in
time domain is generated by interpolating impedance logs derived from wells having sonic and density logs. Third input viz. time horizons interpreted over the conventional seismic volume guide the lateral variations of impedance in the model. The wavelet required for inversion is extracted at a number of well locations to give best synthetic-seismic correlation. QC is carried out for selection of inversion related parameters before running the inversion. The impedance volume obtained is used to derive total impedance attribute over the BCS unit required for mapping the reservoir rock.

As BCS unit top is not a correlatable seismic event, selecting a suitable and accurate window for deriving the above attributes corresponding to the unit has been an issue. A mathematical two-way time (twt) surface corresponding to the top of BCS unit has been worked out in the following manner:

- Inversion brought out clear definition of basement top as basement impedance is substantially higher than the overlying sediments. Basement which is correlated as trough on amplitude seismic volume is fine tuned on inverted volume (Figs.6 & 7).
- Around forty wells have sonic logs recorded up to the basement. The average velocity from BCS unit top to basement is calculated for each of these wells and is 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 BCS interval in the area.
- The twt thickness grid is subtracted from fine tuned basement horizon to get the time surface mathematically corresponding to the top of BCS unit (Fig.7).
- Impedance of the characteristic shale is 6200 units as observed on the well logs. This impedance value of 6200 multiplied by the total number of samples in the BCS interval gives the total impedance of shale if sand is considered to be absent.
- Difference of total observed impedance and 6200 x no. of samples over the BCS unit is calculated. Higher values of the difference are indicative of the contribution coming from thicker reservoir facies. This difference attribute overlain by the structure map (Fig.8) at BCS unit top brings out the strati-structural reservoir distribution (Fig.9).

**Conclusions**

- This methodology has effectively utilized the information in the data.
- Average shale impedances in a unit are generally constant in case of least variation in depth. Shale in BCS unit is observed to have impedance value of 6200.
Fig. 7 Basement correlated on trough (Cyan) is fine tuned (red color) on the inverted volume at interface of impedance contrast. BCS unit top (white color) is mathematically worked out. Relatively higher impedance values (yellow & cyan colour) are interpreted as reservoir rock in the BCS interval.

Fig. 8: Time structure map at BCS unit top map

Fig. 9: Difference impedance attribute over Basal Clastic Sand unit overlain by Time structure map at BCS unit top.
BCS unit top, not being interpretable event on seismic but necessary for deriving any window attributes is derived mathematically with the help of well logged sonic, after fine tuning the basement on inverted volume.

The study has brought out the distribution of reservoir rock within the BCS unit. The map shows the presence of BCS reservoir rock in areas where it was earlier thought to be absent.

References


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