Calibration of Sonic Logs for Seismic Applications in Upper Assam
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ABSTRACT: Merging of data from seismic surveys and well logs in geophysical exploration is a part of synergistic approach for better understanding of geological model of the field. Sonic log provides continuous records of different formation velocities especially at shallow and intermediate depths, which may not be interesting from reservoir point of view. Exact knowledge of velocities is used for time to depth conversion, computation of synthetic seismic sections, migration and processing of geologically complex areas. Once hydrocarbon trap is proved by a discovery well, the whole seismic interpretation is to be re-looked for a new range of possibilities, resolution and detailed study. Delineation of known producing formations then becomes more discernible on seismic sections studied in conjunction with geophysical borehole measurements. While using sonic logs for seismic purposes, one has to adjust the sonic logs according to seismic measurements in the boreholes because sonic times obtained through the integration of sonic logs usually differ from those obtained by means of a well seismic. The reasons for drift range from basic discrepancies between two approaches due to different geometry / frequency of measurement principles etc. to more trivial disturbances in the formation i.e. alteration / invasion, which affects the sonic logs resulting in cycle skipping, detection of mud arrivals in large holes. Since the check shot / VSP method is simpler and corroborates with reflection survey results, sonic is more susceptible. Therefore, it is necessary to calibrate the sonic logs in order to eliminate these possible errors to use it for seismic application for a particular area. In the present study interval velocity, average formation velocity computed from both one way seismic time and integrated sonic time data available over sixteen wells spread all over Upper Assam oil fields show negative drifts for the calibration of sonic transit time. Amount of drifts is more in Girujan Clays about more than half of the total drift. Interval velocity values derived from seismic one way time are showing finer variations, which are some times cyclic in nature i.e. higher velocity followed by lower one, as compared to interval velocity values derived from sonic. These variations will result in creating fictitious reflections on synthetic seismograms, which are not seen on log measurements. Block shifting of sonic log ensures integrated travel time at par with seismic one-way time by preserving formation signatures required for seismofacies mapping. It is worth mentioning that sonic log has not lost even a bit of its grace as continuous velocity log even with recording of well seismic data / VSP. This method of correcting sonic logs for seismic applications will certainly provide a value addition for the realistic interpretation of seismic data in future study of Upper Assam fields and the method may be extended for other area too.

INTRODUCTION

Merging of data from seismic surveys and well logs in geophysical exploration is a part of synergistic approach for better understanding of geological model of the field. Sonic log provides continuous records of different formation velocities especially at shallow and intermediate depths, which may not be interesting from reservoir point of view. An exact knowledge of velocities is used for time to depth conversion, computation of synthetic seismic sections, migration and processing of geologically complex areas. As such velocity is an extremely important parameter for seismic interpretation. Once hydrocarbon trap is proved by a discovery well, the whole seismic interpretation is to be re-looked for a new range of possibilities, resolution and detailed study. Delineation of known producing formations then becomes more discernible on seismic sections studied in conjunction with geophysical borehole measurements. One feels almost apologetic to mention this, but there have been cases where dry holes have been drilled because no one has gone back to look at seismic sections where producing sand was as plain as pikestaff (Anstey, 1977).

While using sonic logs for seismic purposes, one has to adjust sonic logs according to seismic measurements in the boreholes because sonic times obtained through the integration of sonic logs usually differ from those obtained by means of a seismic pulse (well velocity surveys/ check shot surveys/ VSP). The reasons for drift, range from basic discrepancies between two approaches-geometry, frequency etc to more trivial disturbances to sonic readings caused by cycle skipping, detection of mud arrivals in large holes, formation alteration and/or invasion (Strike, 1971, Gretener, 1961 and Goetz, etal, 1979).

Sonic measurements are susceptible to errors due to a variety of factors:
Detection triggered by noise before the signal arrives.

Hole enlargement in which case mud signal will arrive first.

Signal stretch resulting in increased travel time.

Cycle skip or negative stretch, when the signal recorded by near receiver is weaker than the signal recorded by far receiver.

Difference in frequency between signals emitted by seismic source (~ 50 hz) and the sonic signals (around 20 to 25 KHz), speed of sound being dependent on frequency.

Formations, which have lower sonic velocity than mud due to presence of gas or poor compaction.

Filtrate invasion which, when it replaces a lighter slower fluid (such as oil or specially gas, results in an increase of velocity in invaded zone in relation to the real velocity in virgin zone.

High apparent dips, causing acoustic signal to follow a refracted path, which is shorter than one along the borehole.

In spite of these reasons, either sonic or check shot measurement may be wrongly made, due to technological inadequacies or malfunctions. Since the check shot / VSP method is simpler and agrees with reflection survey results, sonic is more susceptible. Therefore, it is necessary to calibrate the sonic logs in order to eliminate many of these possible errors to use it for seismic application in a particular area. This must be done before converting the depth scale to time scale using time depth relationship established through sonic logs. Calibration is done either by using check shots or by using VSP technique.

Interval velocity, average formation velocity are computed from both one way seismic time and integrated sonic travel time data available in sixteen wells spread all over Upper Assam oil fields. Time, velocity and drift curves are presented separately for each well. Average and interval velocity curves are presented in same scale with different colours for seismic and sonic derived valves. Drift curves available in four wells are also given in tabular for reference.

**METHODOLOGY**

Seismic time is the check shot or VSP time corrected to vertical and reduced to the seismic reference datum. Seismic Reference Datum (SRD) for the area under study is 91 meters above mean sea level. Sonic time i.e. integrated travel time (ITT) is available as a function of depth i.e. sometimes referred as log depth with K. B. as reference datum. Seismic one-way / two way time is generally available at SRD.

Seismic time SRD depths are converted to log depth by adding (K.B – SRD) to SRD depths. One way sonic time is obtained from ITT pips on sonic log for corresponding SRD depths converted as log depths. Starting value of ITT is taken as value of seismic time at a tie point depth.

Average and interval velocities at particular depth are computed from both sonic and seismic time using following equations.

\[
V_{avg} = \frac{\text{depth}}{\text{time}} \quad \text{and} \quad V_{int} = \frac{(\text{depth}2-\text{depth}1)}{(\text{time}2-\text{time}1)}
\]

Drift is defined as the difference between seismic time and integrated sonic time i.e. Drift = Seismic time – Sonic time. At tie point both seismic time and integrated sonic time are made equal. In present case, both are made equal to seismic time and then drift is computed at every VSP depth converted to log depth as mentioned earlier. The successive values obtained are then plotted as a function of log depth, which produces drift curve. For a given pair of depths, difference in drift between the two depths is the correction, which must be applied to the sonic travel time.

Now zones are chosen, in which the character of the sonic interval velocity is about constant or according to stratigraphy viz. Tipams, Barail Coal Shale or Barail Main Sand, Kopili etc. In each zone, drift points are fitted by a segment of straight line. These segments are joined at knees, which form the common boundaries between one zone to the next.

The drift curves are used to adjust the sonic logs. On the drift curves, the slope of the segment of the straight line joining two consecutive knees is the gradient of the drift, expressed in microseconds/ft is the average drift, i.e. correction to be applied to the sonic transit time.

When slope is negative, drift is said to be negative, which means that sonic time is longer than seismic time. Finally, a corrected sonic transit time curve is to be obtained by applying respective drift value for a particular zone.

**RESULTS**

Interval velocity, average formation velocity are computed from both one way seismic time and integrated sonic travel time data available in thirteen wells (Fig. No. 1) spread all over Upper Assam oil fields. Velocity and drift curves are
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Figure 1: Location Map of Upper Assam Oil Fields

Figure 2: Velocity plots and drift analysis of Chakimukh # X

Figure 3: Velocity plots and drift analysis of Changmaigaon# X

Figure 4: Velocity plots and drift analysis of Charali# XX
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Figure 5: Velocity plots and drift analysis of Demulgaon # X

Figure 6: Velocity plots and drift analysis of Geleki # XXX

Figure 7: Velocity plots and drift analysis of Kuargaon # X

Figure 8: Velocity plots and drift analysis of Lakwa # XX
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Figure 9: Velocity plots and drift analysis of Laxmijan # X

Figure 10: Velocity plots and drift analysis of Nazira # XX

Figure 11: Velocity plots and drift analysis of Panidihing # X

Figure 12: Velocity plots and drift analysis of Safrai # X
Table 1: Cumulative Drift Values in Milliseconds for Integrated Transit Time

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Well No.</th>
<th>Depth Interval (m)</th>
<th>Total drift Values (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Chakimukh # X</td>
<td>1700 - 4485</td>
<td>-175</td>
</tr>
<tr>
<td>2.</td>
<td>Changmaigaon # X</td>
<td>1650 - 3150</td>
<td>-40</td>
</tr>
<tr>
<td>3.</td>
<td>Charali # XX</td>
<td>1725 - 3775</td>
<td>-26</td>
</tr>
<tr>
<td>4.</td>
<td>Demalgaon # X</td>
<td>540 - 3440</td>
<td>-101</td>
</tr>
<tr>
<td>5.</td>
<td>Demalgaon # XX</td>
<td>1925 - 3750</td>
<td>-15</td>
</tr>
<tr>
<td>6.</td>
<td>Geleki # XXX</td>
<td>1475 - 4350</td>
<td>-123</td>
</tr>
<tr>
<td>7.</td>
<td>Kuargaon # X</td>
<td>2400 - 4000</td>
<td>-45</td>
</tr>
<tr>
<td>8.</td>
<td>Lakwa # XX</td>
<td>2375 - 3550</td>
<td>-35</td>
</tr>
<tr>
<td>9.</td>
<td>Laxmijan # X</td>
<td>500 - 4000</td>
<td>-101</td>
</tr>
<tr>
<td>10.</td>
<td>Nazira # XX</td>
<td>1425 - 3381</td>
<td>-86</td>
</tr>
<tr>
<td>11.</td>
<td>Panidihing # X</td>
<td>1550 - 3875</td>
<td>-18</td>
</tr>
<tr>
<td>12.</td>
<td>Safrai # X</td>
<td>1771 - 4346</td>
<td>-172</td>
</tr>
<tr>
<td>13.</td>
<td>Sonari # X</td>
<td>710 - 3510</td>
<td>-94</td>
</tr>
</tbody>
</table>

Table 2: Drift Values (microsec/ft) against different Formations for the calibration of Sonic Transit Time

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Well No.</th>
<th>Girujan Clays (1 – 3)</th>
<th>Tipams Clays (4 – 6)</th>
<th>BCS</th>
<th>BMS</th>
<th>Kopili</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Chakimukh # X</td>
<td>- 26.38 - 12.85</td>
<td>- 12.06 - 16.04</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Changmaigaon # X</td>
<td>- 22.06 - 3.42</td>
<td>- 7.30</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Charali # X</td>
<td>- 10.21 - 5.62</td>
<td>- 5.41 + 3.24</td>
<td>-</td>
<td>-9.41</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Demalgaon # X</td>
<td>- 19.94 - 3.84</td>
<td>- 2.25</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Demalgaon # XX</td>
<td>- 4.18 - 3.68</td>
<td>- 1.57</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Kuargaon # X</td>
<td>- 8.71 - 10.69</td>
<td>- 10.69 - 6.90</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Lakwa # XX</td>
<td>- 6.53 - 10.85</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Laxmijan # X</td>
<td>- 5.80 - 15.21</td>
<td>- 11.78 - 16.52</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Nazira # XX</td>
<td>- 14.31 - 29.31</td>
<td>- 2.83 - 1.30</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Panidihing # X</td>
<td>- 12.29 - 8.01</td>
<td>- 8.01 - 6.31</td>
<td>-2.15</td>
<td>-3.5</td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>Sonari # X</td>
<td>- 12.57 - 12.37</td>
<td>- 5.10</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DISCUSSION

Product of density and sonic velocity measurements obtained in a borehole is generally used to derive acoustic
impedance curve, which in turn is used to generate a reflectivity log or reflection coefficient defined as relative contrast of acoustic impedances of two successive zones marked with boundary as acoustic discontinuity. Convolution of reflectivity log with a source wavelet produces synthetic seismic trace or seismogram. When this is compared with the real seismic trace, it becomes possible to depth match the real trace and to interpret it in terms of seismofacies. This is how well logs contribute to the interpretation of seismic profiles and thus provides an essential link between surface geophysics and geology.

Data provided by the density and sonic tools can not be used in their raw form, as log measurements are subject to the influence of parasitic factors such as an invaded zone or bad hole conditions, and must first be corrected before calculating the acoustic impedance reflection coefficients. Density log responds mainly to invaded zone due to its shallow depth of investigation. Density value will be too high in case of replacement of light hydrocarbon especially gas, and it must be corrected to give density of virgin zone. However, in case of Upper Assam oil fields, hydrocarbon effect is not seen on density measurement and does not require correction for invasion of mud filtrate on it. As such calibration of density log is not considered in this report.

Well log editing has two major facets, first to recognize that incorrect data have been recorded and second to determine better values to substitute for the incorrect (Ausburn, 1977). In present case, sonic log against washed/caved shale are not corrected since no appropriate velocity depth relation is presently available for shale in the study area. Another point of establishing this relationship is more difficult task in absence of unwashed shale zones in the available logs.

Many authors have discussed physical and technological limitations of sonic log measurements in the past (Dupal, etal, 1977, Thomas, 1984, Peyret and Mons, 1984). Negative and positive drifts are explained as cycle skipping and dispersion of velocity respectively. It is very easy to explain the negative drift observed against most of the formations in Upper Assam oil fields. Anomalous negative drift on ITT in Chakimukh # X ( -175 msec), Geleki # XXX ( -123 msec) and Safrai # X ( 172 msec) is noticed and more than half of the drift is attained in Girujan Clays itself. The same phenomenon is observed in all the wells. Due to the swelling nature of the clays, sonic log is reading anomalously higher value of transit time. Sonic tool is not able to read virgin zone velocity due to its shallow depth investigation. Positive drift some times noticed in Barail Coal Shale may be attributed to the of invasion of mud filtrate causing higher velocity in comparison to the virgin zone having gas/ volatile material in cleat porosities.

Although sonic measurements with sample interval of 6" with a higher resolution up to 2 feet, interval velocity values derived from seismic one way time are showing finer variations, which are sometimes cyclic in nature i.e. higher velocity followed by lower one, as compared to interval velocity values derived from sonic ITT. These variations will result in creating fictitious reflections on synthetic seismograms, which are not seen on log measurements. This is probably due to the early or late picking of first arrival value on VSP due to its flat nature / low frequency wavelet (~ 50 Hz) as compared to sonic wavelet (~ 20 - 25 KHz). Spurious nature is further confirmed by the absolute value of formation velocity up to 8.0 km/sec, which is not possible in nature (Fig. No. 36, 42 and 45).

There has been a common practice to generate continuous velocity log derived from counting of ITT pips on sonic log within a successive interval of 10 mts. Velocity values plotted as function of ITT in a compatible scale of one way time seismic section, provides an alternate of synthetic seismogram for seismofacies mapping within major sequences. As this method is based on the concept of displaying of sonic velocity as function of ITT in seismic one way time scale, drift values i.e. corrections are presented for both in the present report for the generation of CVL for seismofacies mapping.

**CONCLUSION**

- Negative drifts for the calibration of ITT as well as sonic transit time, are generally observed in all the wells. Amount of drifts is more in Girujan Clays. Actually, more than half of the total drift is attained in Girujan Clays itself.
- Cumulative drift values in milliseconds to be applied for the calibration of ITT and drift values in microseconds/ft to be applied to correct sonic Delta T values against different formations in different wells presented in tabular form to correct the sonic log for seismic applications.
- Although sonic measurements with sample interval of 6" with a higher resolution up to 2 feet, interval velocity values derived from seismic one way time are showing finer variations, which are some times cyclic in nature i.e. higher velocity followed by lower one, as compared to interval velocity values derived from sonic integrated travel time. These variations will result in creating fictitious reflections on synthetic seismograms, which are not seen on log measurements.
Block shifting of sonic log ensures integrated travel time at par with seismic one way time by preserving formation signatures required for seismofacies mapping. It is worth mentioning that sonic log has not lost even a bit of its grace as continuous velocity log even with recording of well seismic data/VSP.

ACKNOWLEDGEMENTS

Authors are thankful to ONGC authorities for their kind permission to present and publish this article. Technical discussions with Shri J. L. Srivastava, Dy. G.M.(W), Shri U. C. Bhatt, Dy.G.M.(W) and other colleagues of Well Logging Services, ONGC, Nazira, Assam, are gratefully acknowledged. Critical review of the paper by Shri Aloke K. Bhanja, is thankfully acknowledged. Special thanks are due to I/C RCC, GSD, ONGC, Jorhat, for providing VSP data for the present study.

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