Generation of High-Resolution Synthetic Seismogram from Image Logs for Advanced Reservoir Applications

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Summary

Impact of seismic data with a resolution close to borehole image logs would be incredible in the ongoing efforts for accurate reservoir characterisation and modelling. In a modest effort, a method has been developed for generating high-resolution synthetic seismogram from the image logs.

In conventional method, both sonic and density logs are used for generating synthetic seismograms, but they are highly sensitive to borehole conditions rather than thin sedimentary beds and boundaries. In order to echo the presence of finer formation features in seismic domain, a high-resolution data that is more sensitive to the formation rather than to the borehole condition is needed.

In the new method, a high-resolution resistivity curve that has been derived from an image log is used as the input log for making the synthetic seismogram. The resistivity log was converted into an equivalent acoustic log. The newly generated acoustic log was then calibrated with the relatively low-resolution sonic log from the same interval. After the log calibration, an acoustic impedance log with a closer resolution to the input log has been generated, using a high resolution sampling technique. Then, a synthetic seismogram of comparable resolution to the original image log was generated from the acoustic impedance log.

The synthetic seismogram has achieved a resolution in the order of few decimetres. It could also reproduce most of the reservoir architectural elements and barriers even in bad borehole sections. The results could be used in advanced reservoir applications such as accurate identification and correlation of thin beds, marker beds and sedimentary architectural elements.

Introduction

High resolution data with low reservoir coverage (e.g. image logs) and low resolution data with high reservoir coverage (e.g. seismic data) are available in the petroleum industry for decades. However, both the high resolution and coverage together in a single set of data has not yet been possible (Christie et al.1995). In the modern days of high-resolution reservoir characterisation and modelling, efforts are made in all directions for increasing the resolution of seismic data to a comparable level with the resolution of well log data (Perra et al., 2003, Barkved et al., 2004). Experiments are also carried out to convert the high resolution log data into seismic domain for a better correlation and linking between the high resolution and high coverage data.

The resolution of modern resistivity image logs is incomparable to any other logs. Moreover, the image logs are versatile in the sense that they are comparable to core data in revealing reservoir architecture, quality and complexities (Watanabe, 2002, Lawrence, et al., 2003). Flexibility of converting the high resolution borehole data into seismic mode and thereby correlation and refining of present day high resolution borehole or surface seismic data will bring immense value for detailed characterisation and modelling of subsurface. In this modest effort, a high resolution resistivity log from an image log has been transformed into a synthetic seismogram without loosing much of its resolution. The high resolution synthetic seismogram also preserves the acoustic properties, which were observed from a sonic log based synthetic seismogram, of the encountered rocks. This method is been carried out as the first step towards up-scaling the high-resolution image logs to the high coverage reservoir imaging sonic or surface seismic data for detailed reservoir studies (Chang et al. 1998).

Data and Methodology

A high resolution borehole electrical image log, the high resolution synthetic resistivity (SRES) log that was created by scaling the image resistivity to a shallow resistivity log, a sonic log, and zero offset VSP (Vertical Seismic Profiling) data, all from a clastic reservoir section of a on-land well, are used in this study. Lithology within the well section mainly composed of sandstone, siltstone and shale with occasional beds of coal and limestone.

The raw image log was processed to remove the effects of sticking and slipping and bad buttons. The image was also processed for equalisation of resistivity values among all the individual buttons of the tool. The processed image log was then verified for depth match with other openhole logs and also for sharpness of the image.

The SRES log was generated from the processed borehole image data using a standard scaling method. In this method, the relative resistivity of the image log is scaled to the absolute resistivity from a conventional shallow resistivity log for assigning formation resistivity to the image. In order to preserve resolution and sharpness close to that of the image log, SRES curve from one of the pads of the image log was used in further applications. The SRES curve has a resolution of 3cm. Due to dipping of sedimentary features, it is possible to loose resolution and sharpness of the average SRES of all the pads and flaps. As there is no nodular feature within this sedimentary section, selection of SRES from a single pad does not affect true representation of the formation. Moreover, it has an added advantage of avoiding effects of bad borehole condition, particularly due to borehole breakout, on the SRES curve.

The sonic log from the well was edited for borehole environmental corrections, as a common practice of log preparation in the generation of synthetic seismogram.

The SRES log was converted into pseudo sonic curve using the Faust equation (Faust, 1953, Rudman et al., 1975) and named DT-SRES. The DT-SRES curve was then scaled to the original sonic log from the section, using the same methodology of scaling image log to a shallow resistivity log. The scaled DT-SRES log was then verified with the sonic log not only for its match with the sonic log, but also for better resolution. All the rock types within the interval, except coal, have convincing match between the sonic and scaled DT-SRES. Against the coal intervals, the DT-SRES was showing a positive deflection in contrary to the negative deflection shown by the sonic log. This is because of the opposite electric and acoustic properties of coal. This reversal effect was overcome by log editing with a mirror log of the DT-SRES in the coal interval. Thus, a high resolution synthetic sonic curve (DT-SRES) was generated from the image log for the preparation of synthetic seismogram.

For the preparation of a synthetic seismogram, initially the Reflection Coefficient (RC) series is derived from a sonic log calibrated with the check shot survey. When generating a seismic trace from sonic log at a sampling rate of 1ms, which is present-day standard in the industry, the log resolution is compromised to match with surface seismic. In this study, in order to preserve the resolution of DT-SRES curve a workflow was devised by scaling the log by 5 times of its value in both directions of the grid i.e depth and measurement. The up-scaled log is then calibrated with the seismic times, derived from a zero offset VSP data of the same well.

The calibration was done to take care of the dispersion variations in the borehole diameter, invasion of porous formations by mud filtrate and chemical alterations of shale by hydration.

The calibrated sonic times from the field DT, are used to convert from depth to time domain. The logs (field Sonic and DT-SRES) are resampled in the time domain at 0.1ms using the high frequency sampling technique. Acoustic Impedance is derived from the resampled logs, which in turn is used to derive the RC series. To generate a synthetic seismogram, the RC series is convolved with the zero phase normal polarity Ricker wavelet at 30 and 60 Hz). The synthetic seismograms are then downscaled by the factor, which was originally used for up scaling the curves, so that the seismograms were brought back to original scale.

Results

Results from this study are mainly divided into two parts, 1) generation of the high resolution, synthetic sonic log (DT-SRES), which has been calibrated with a conventional sonic log, from the borehole image log, and 2) generation of a high resolution synthetic seismogram from the acoustic impedance log using a high frequency sampling technique.

The synthetic sonic log (DT-SRES) is virtually a high-resolution sonic log, which represents the absolute travel time of the formation at a resolution of 3cm (Figure 1). In the studied section of clastic sedimentary deposits, almost all the significant beds and sedimentary architectural elements have been reflected in the DT-SRES log.

In addition, the sharp and distinct changes in the travel times against the bed boundaries have also been able to retain in the synthetic sonic log (Figure-1). The preservation of the above qualities that are characteristics to the image log in the synthetic sonic log makes the DT-SRES log exceptional for generating synthetic seismogram.

As a padded tool was used for acquiring the image and also the SRES log is from the best image of a single pad, the borehole environment impact in the DT-SRES log is very less than that in the sonic log (Figure-1). The padded tool with a maximum expansion size of 21 inches enabled to read the resistivity even in moderately washed out zones, which are mainly the zones of coal and shale interbeds. In the washout zones, the conventional sonic log is less sensitive to the interbeds of coal and shale. However, the sharp resistivity contrast between the shale and coal beds, as it is observed in the original image log, is distinctly differentiated in the DT-SRES log as well.

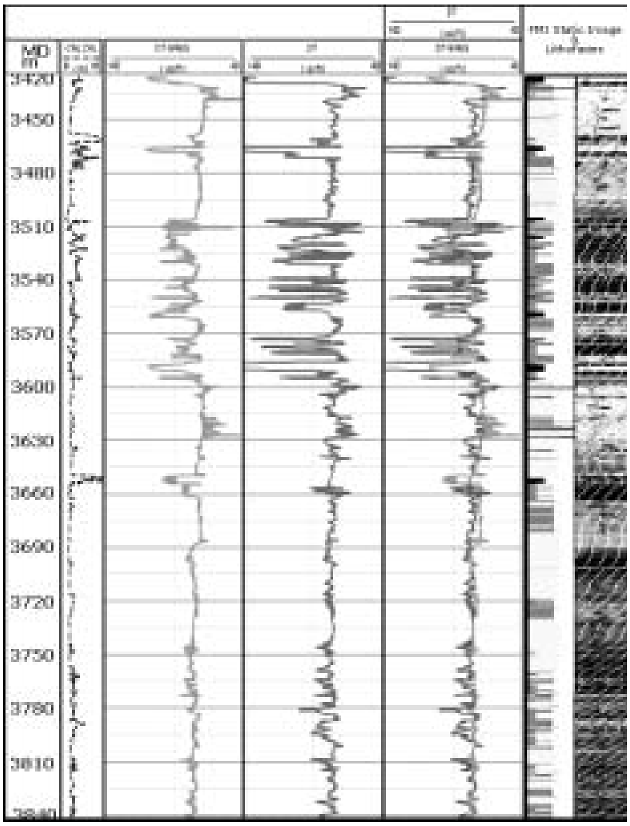

Fig.1: DT-SRES log with an increased resolution and better correlation with formation in comparison with sonic log. Tracks 1 to 6 contain depth in MD, Caliper, DT-SRES, DT, DT-SRES&DT and FMI Static Image & Lithofacies respectively.

The high-resolution synthetic generated from the DT-SRES log has better accuracy to the bed boundaries and it is less affected by the borehole conditions, especially the breakouts and washouts (Figure-2).

It is also observed that the effect of small scale borehole ruogosity that impart variations in sonic reading could also be minimised by selecting original SRES curve from the best pad of the image. Thin beds of sandstone, shale, coal and limestone are also well reflected in the new seismogram with better depth accuracy and distinction than that is possible from the conventional sonic log (Figure-3 & 4).

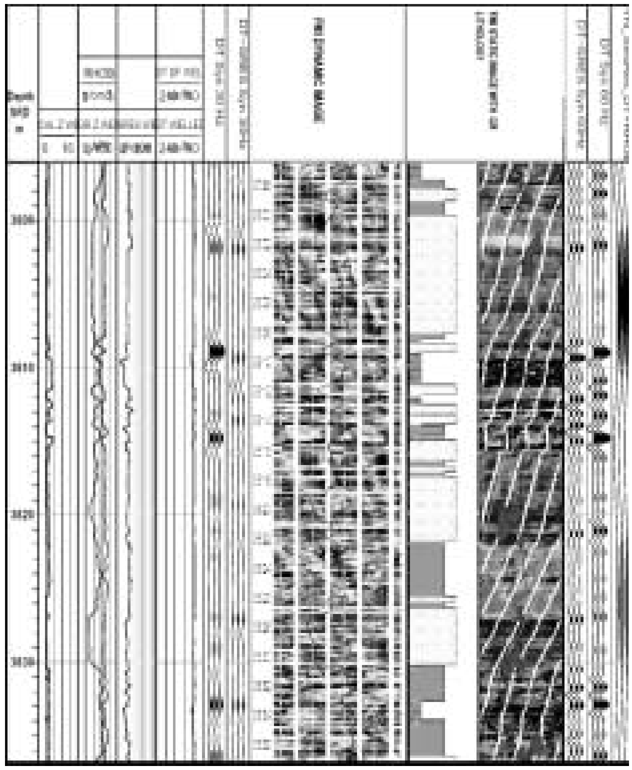

Fig.2 : High resolution synthetic generated from the DT-SRES and DT logs show that DT-SRES based syntheic gives better acuracy of depth (e.g. at 3810m MD) and it is less affected by bad borehole conditions (e.g. at 3824m MD).

The high-resolution borehole image logs revolutionalised the sub-surface interpretation, especially the visualisation and interpretation of finest sedimentary architecture and thereby reservoir properties, in and around the borehole wall (Watanabe, 2002, Lawrence, et al., 2003). The newly generated synthetic seismogram, which is the seismic expression of the finest details, is the first step of up-scaling the luxury of the detailed information from borehole to the reservoir scale. In the context of new technologies such as, a) high-resolution borehole seismic acquisition and processing that can preserve the high frequencies from deeper depths, and b) high resolution sonic imaging (Chang, 1998) that could image geological bodies tens of meters away from the borehole, this new technique has a significant role in carrying out geological and reservoir interpretations beyond the borehole wall. For instance, in a

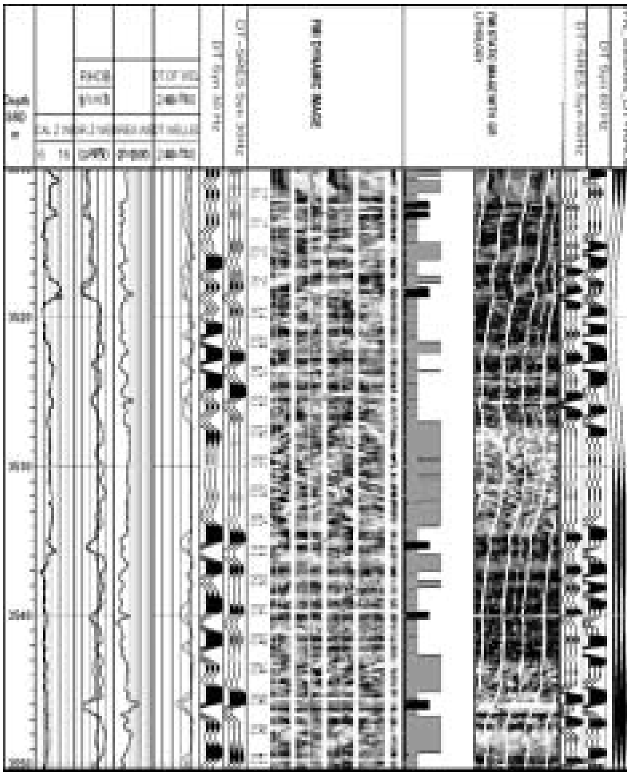

Fig.3: High resolution wavelets generated from the DT-SRES and DT logs show that DT-SRES based wavelet gives better acuracy to the thin beds of coal (e.g. at 3513m MD, 3518m MD, 3535m MD and 3540m MD).

classic fluvio-deltaic environment (like the one used in this study) channel width, size and shape of sand bodies, extent and continuity of thin coal and limestone beds etc. can be identified by correlating the high-resolution seismogram and a sonic or borehole seismic image.

Further modifications in the present technique are possible for the betterment of the results. The scope for improvement of results are primarily related to the use of better, probably customised, equation for converting resistivity log into sonic log, and also to the use of a high resolution density log that does not force DT-SRES to compromise its resolution while generating the high-resolution synthetic seismograms.

Conclusions

The high resolution synthetic seismogram distinctly echoes the finest sedimentary architecture of the formation with much more accuracy of depths, compared to a conventional synthetic seismogram. These distinct characteristics of the high resolution seismogram enable detailed characterization and correlation of reservoir architectural elements for better understating and modeling of complex reservoirs.

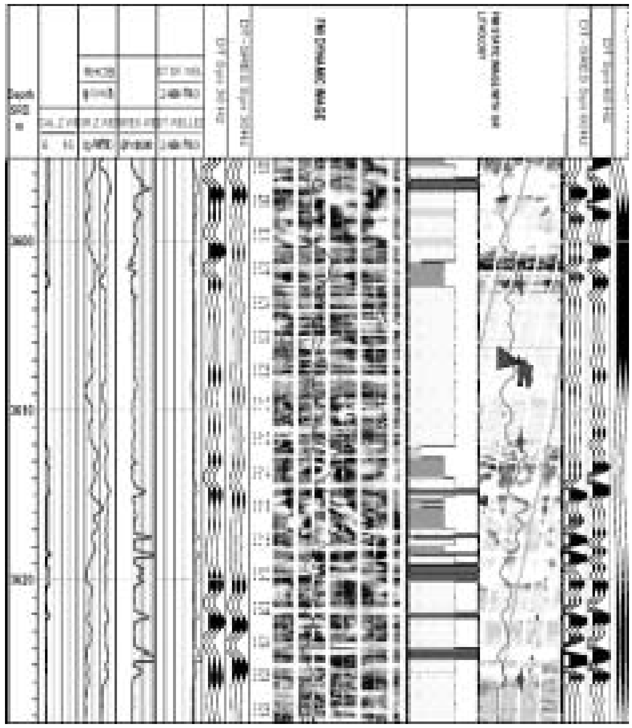

Fig.4: High resolution wavelets generated from the DT-SRES and DT logs show that DT-SRES based wavelet gives better acuracy to the thin beds of limestone (e.g. at 3596m MD, 3614m MD, 3619m MD, 3622m MD and 3624m MD).

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Views expressed in this paper are those of the authors only and may not necessarily be of ONGC.

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