Application of "thickness of amplitude" 3-D seismic attribute in mapping of pay thickness in a thin hydrocarbon reservoir

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Abstract

The "thickness of amplitude" attribute is defined as total time length (in milliseconds) of amplitudes that exceed a threshold value of amplitude in the target layer within 3-D data volume. The threshold value is estimated by analysing the reflection response of the subsurface layers. It depends on impedance contrast, geology and reflection wavelet characters (polarity, phase, frequency, amplitude etc.). This attribute extraction was applied for pre-drill estimation of time-thickness of thin sandstone pay in the area. The thin pay was identified through integrated interpretation of 3-D seismic data. The geologic thickness (in meter) of the thin pay was estimated from thickness of amplitude through multiplication by interval velocity (m/s) of the pay. The pay thickness is one of the important parameter along with area, porosity and saturation for estimation of hydrocarbon potential of the reservoir and decision on drilling of wells. In this study the thickness estimates were found valid with accuracy of more than 80 % after drilling the well for discovery. Concepts, methodology and relative merits and novelty of the method are discussed in the paper.

Introduction

Pre-drill estimates of reservoir pay thickness and its areal extent along with guess for fluid type, porosity and saturation are essential information for reservoir characterization and assessing the hydrocarbon potential of the reservoir layer in the study area.

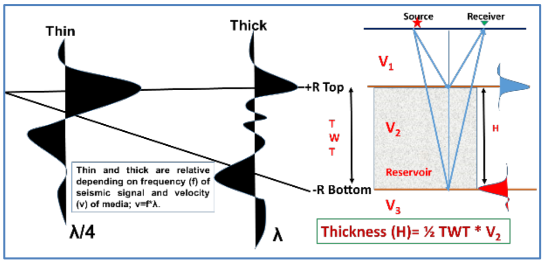

Fig. 1 Sketch (not to scale) concept of thick and thin beds with respect to given wavelet character (wavelength, frequency, amplitude, polarity and phase). The thickness is described in terms of wavelength (λ).

The pay may be thin (below seismic resolution) or thick (pay top and bottom easily identifiable on seismic) (Fig. 1). In the case of thick pay zones where top and bottom interfaces are identifiable by separate seismic reflection events, the thickness will be half of two way travel time within layer multiplied by interval velocity (Fig. 1). In case of thin pays where reflections from top and bottom interfaces are not separable due to tuning, we may get single composite wavelet representing both top and bottom reflections. For a given impedance contrast, the amplitude of the composite wavelet is found to be maximum when thickness is equal to 1/4th of the wavelength (λ) of seismic wave. The amplitude maxima is caused by tuning effect where reflections with opposite sign from top and bottom interfere constructively. The tuning effect is very widely studied in the seismic interpretation (Brown 2004, Widess 1973). If not understood properly, the tuning may result in erroneous inferences regarding thickness, facies (lithology), depositional geometry and Direct Hydrocarbon Indicator (DHI) analysis etc. When thickness is smaller than (λ/4), amplitude decreases linearly with the thickness (Fig. 2). In the figure, amplitude and time-thickness within specified time interval are cross plotted. The amplitude maxima is observed at 14 ms time-thickness which is also the tuning thickness. For thicknesses smaller than tuning, amplitude and thickness have proportionate relationship. For thicker pays amplitude from top and bottom is independent of thickness and depends on amplitude contrast only. In such cases, thickness estimation is straightforward after identification of top and bottom reflections and their respective two way travel times. The thickness-amplitude relationship can be used for mapping of reservoir thickness and assessing hydrocarbon potential of the thin layer.

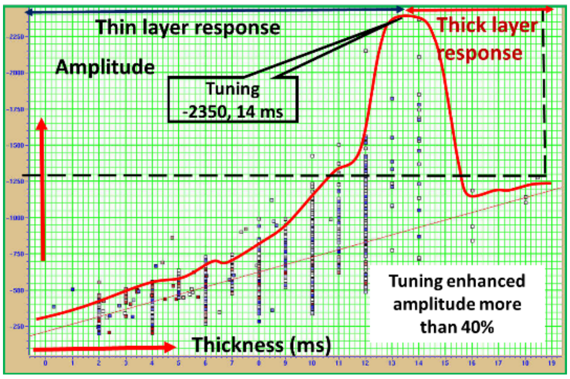

Fig. 2 Cross-plot showing linear decrease of amplitude with decrease in thickness. It was generated during execution of attribute extraction. It demonstrates both the concept and the result.

Theory and Method

In case of a simple clastic geologic setup (Fig. 3) where a thin reservoir layer (sandstone) is embedded in non-reservoir layers (shales) and tuning occurs, the amplitude of reflections is also affected by thickness variations of reservoir layer (Fig. 2) though reflection amplitude is mainly function of impedance contrast between layers across interface. In figure 3 the seismic section shows a high amplitude anomaly (bright spot, red event) enclosed in relatively low amplitude (blue) events. The equivalent causative geological model for the observed seismic response is shown in the left part of the figure. The thin sandstone reservoir layer is sandwiched in shale layers.

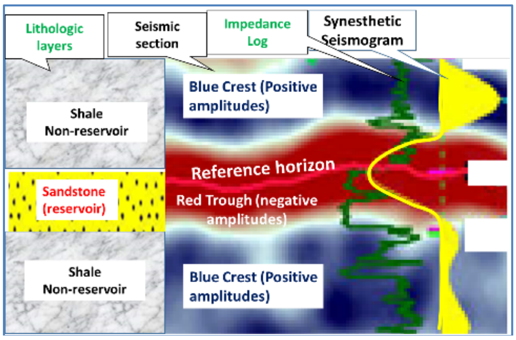

Fig. 3. The simple shale-sand sequence model and its reflection response. Impedance log (green curve) and synthetic seismogram (yellow trace) are overlaid on the seismic section. The pink colour reflector (reference horizon) represents the top of low impedance pay sand. *(Note: Initially logs and synthetic were not available as well was drilled subsequent to study)*

The reservoir layer is considered "thin" if its thickness is lesser than 1/4th of the wavelength of the seismic wave. The wavelength ((λ=v/f)) is function of velocity (v) and frequency (f) of seismic wave. The velocity, an intrinsic property, depends on many properties and geologic factors (density, lithology, geologic age, depth of burial, porosity, fluid content, fluid saturation etc.) of the geologic layers and frequency is affected by many wave propagation properties (attenuation, absorption etc.) of the medium along with seismic signal source characteristics. Under the assumption that all the intrinsic and propagation characteristics are constant within the areal extent of the reservoir, the amplitude of reflected wavelet dominantly depends on thickness of thin layer. If we can measure total temporal thickness of amplitudes which exceed a threshold value, we can estimate thickness of amplitude within the defined vertical interval (Fig. 4). The threshold value can be signed, that is, either positive or negative. When the amplitude threshold is negative, the output is the time over which the amplitude is more negative than the specified amplitude threshold.

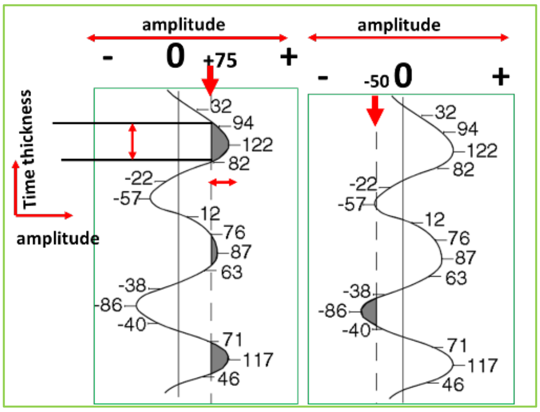

Fig. 4 Sketch showing concept of "thickness of amplitude" attribute. In the left, thickness is shown by vertical arrow and amplitude greater than threshold (+75) is shown by horizontal arrow. Depending upon polarity, the threshold amplitude may be positive (left) or negative (right) both. (*Note: sketch modified from PostStack™ Family Software Reference training Manual of M/s Landmark*)

The workflow for estimating thickness of thin bed is given below:

1. Identification of prospect through integrated interpretation techniques and skills (structural framework building (horizons and fault mapping), seismic attribute analysis, DHI analysis, inversion, AVO analysis etc.). Seismic to well tie and related calibration may not be available, hence data to be visualised and evaluated in terms of two way travel time and respective anomalies (amplitude, frequency, phase, geometry (shape of stratigraphic feature, e.g., channel) etc.).

2. Identification of wavelet and its gross temporal thickness representing the anomaly corresponding to target reservoir layer. For a low impedance pay layer enclosed in high impedance layers the anomaly may be in form of bright spot (negative high amplitude, Fig. 3).

3. Correlation of reference horizon (reflector) depending on polarity and phase of seismic data. For a zero phase wavelet with positive (American) polarity, reference horizon may be at middle of the trough (negative pulse) of the wavelet (Fig. 3) (impedance of reservoir layer is lower than enclosing shales). In Fig. 3 the top and bottom of pay are not resolved on the seismic section. A composite high amplitude trough centered at reference horizons represents the pay zone. The amplitude and width of composite trough is assumed to be dependent on thickness of pay sand.

4. Preferentially, scaling of seismic volume in integer storage data format (8 bit, 16 bit) for fixing threshold amplitude value. The 8 bit and 16 bit integer represent values ranging in -128 to 127 and -32768 to 32767 respectively.

5. Identification of appropriate time window with respect to reference horizon in which thickness of amplitude is to be mapped in the data volume. The reference horizon may be flattened for better visualization of time window and amplitude (Fig. 5). Horizon slices of various attribute volumes extracted above and below the reference horizon may be helpful in deciding the appropriate time window.

6. Identification of threshold amplitude value depending on background amplitudes of interfaces where target reservoir is not present. In an 8 bit integer scaled seismic data volume, the amplitude value -40 (about 1/3rd of maximum amplitude (-128) may be taken as threshold value.

7. Estimation of time thickness of amplitude within specified time and amplitude intervals across the seismic volume using the thickness estimation software which may be available in standard 3-D seismic interpretation software module. The time thickness comes in form of horizon (x, y, Trace No. Line No, and thickness (z value)) on which standard mathematical operations (multiplication, summation etc.) can be performed. If needed a special filter may be applied to smoothen the thickness horizon.

8. Estimation of interval velocity of sandstone reservoir layer. In absence of drilled wells, interval velocity has to be derived from seismic velocity volume. Under the assumption of constant impedance contrast between reservoir and non-reservoir layers, a single interval velocity can be estimated for entire pay layer. In current study interval velocity of pay sand was taken 2950 m/s.

9. Estimation of thickness of reservoir layer by multiplying estimated time thickness with interval velocity. The estimated thickness can be contoured (Fig. 6) and resulting map can be overlaid over structure and other attribute maps for validation and further analysis.

Example

The prospect was identified through structural mapping, attribute analysis and inversion studies using 3-D seismic data (Harilal et.al, 2008, 2009, 2010). During analysis it was found that possible thin sand pays have lower impedance than enclosing shales and are represented by negative amplitude reflections (Fig. 3, Fig. 5). Thickness of amplitude in ms was computed by counting the no of samples in the given time interval (-10 to +10 ms with respect to pay marker (reference horizon) having the specified amplitude range (-40 to -128 units) (Fig. 5). Small negative and all positive amplitudes were excluded from the computation. The time thickness (ms) is product of number of samples and sample interval. In example data volume the sample interval is 2ms.

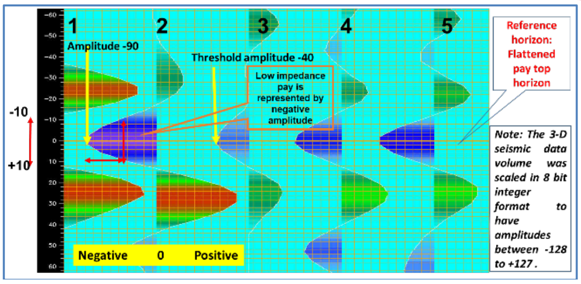

Fig. 5 Illustration showing implementation of the method. 5 traces from the scaled 8 bit integer 3-D volume are shown in zoomed form. The reference pay top reflector is flattened. The computation window is 20 ms (-10 to +10). The threshold amplitude is -40. In trace No 2, maximum amplitude is -90 and thickness of amplitude falling between -40 to -90 is 16 ms.

The generated amplitude thickness map was multiplied by interval velocity of sand-layer (2950 m/s) to get the thickness in meter (Fig. 6). The figure shows a part of thickness map (left) and validation at drilled well (right). Thickness is varying from 6 m to 16 m with value of 15 m at well location. In the well gamma ray, resistivity and impedance logs are shown along with lithologic interpretation. From log interpretation actual pay thickness is 16 m. It is observed that estimated thickness is accurate within 80-100% limit after drilling the well. In figure 3 post-drill seismic to well tie shows perfect match between real seismic and synthetic seismogram generated from log responses. It validates the initial interpretation regarding lithology, impedance contrast, wavelet, reference horizon, and amplitude and time intervals.

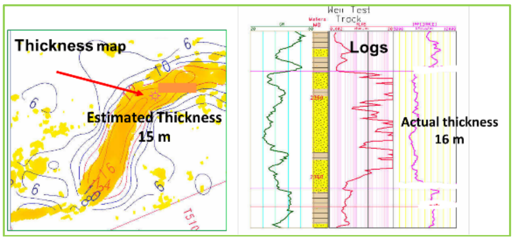

Fig 6. Thickness contour map (left) and well logs (right) showing validation of estimated thickness. The thickness contour map of a small part of 3-D area is shown. After drilling the well, the 15 m estimated thickness was actually found as 16 m.

Merits and Demerits

This method is simpler and faster than other methods, e.g., "Spectral Decomposition" where thickness is estimated indirectly from tuning frequency (f^{max}) (frequency at which amplitude is maximum) and interval velocity. The relationship between time thickness and frequency at which amplitude is maximum is defined as $T=1/4f^{max}$. From velocity and frequency wavelength (λ) is estimated by using the relationship "velocity (v) =

wavelength (λ) *frequency (f)" and thickness will be λ/4. This method is relatively cumbersome as amplitude is to be analysed for every possible discrete frequency within the bandwidth. Also it requires dedicated Spectral Decomposition software module. The output is visualised through horizontal slices frequency-amplitude volume. The standard interpretation workflows for prospect mapping (structural and stratigraphic analysis) are almost same as in the thickness of amplitude method.

The "thickness of amplitude" is direct method where only amplitude threshold and analysis window are to be defined. The method can be used efficiently for thin sand pays embedded in shales. The prerequisites is identification of reflection response of possible pay layer. Thickness-amplitude method requires more interpretational skills than spectral decomposition.

Novelty of method

Estimation of thickness in the specified intervals over well logs (depth versus log value trace) for mapping interesting zones (sand, limestone, coal, porosity etc.) based on sets of cut-off, is routinely used in the petrophysical interpretation. In present study novelty comes in terms of application of existing software for mapping thickness of thin reservoir layer in 3-D volume consisting of time domain traces (travel time versus amplitude/attributes). Sets of Cut-off are in terms of time intervals and amplitude ranges.

Conclusions

The method is based on tuning phenomena of thin layers. The thickness of amplitude attribute is very effective for pre-drill estimation of thickness of thin sand pays. It may provide more realistic pre-drill thickness estimates which is one of the important inputs for the assessment of hydrocarbon potential of the reservoir. Though it requires higher interpretational skills, it is relatively faster and simpler than existing alternative methods and may be easily adapted by seismic data interpreters.

Acknowledgement

The prospect was mapped by standard interpretation software and well published as seen in the references. I am thankful to all co-authors who contributed in initial studies. I am grateful to ONGC and SPG for reviewing and accepting the paper for the Conference.

References

Brown, A. R., 2004, Interpretation of three-dimensional seismic data, sixth edition, AAPG Memoir 42, SEG investigations in Geophysics No. 9.

Harilal, S. K. Biswal and V. Rangachari, 2008, Mapping incised valley fill systems: Application of sequence stratigraphy and 3-D seismic attributes: 7th International Conference, Society of Petroleum Geophysicists, p-117.

Harilal, S. K. Biswal, H. S. Vachak, S. N. Thakur, and S. K. Das, 2009, Application of forward modeling and interpretive processing for mapping of thin and low impedance contrast gas sands using 3-D seismic attributes, SEG Houston 2009 International Exposition and Annual Meeting, p 2612-2616.

Harilal and S. K. Biswal, 2010, Pitfalls in seismic interpretation: Lessons from Oligocene channel sandstones, The Leading Edge 2010, p 384-390.

Widess, M., 1973, How thin is a thin bed?: Geophysics, 38, no. 6, 1176–1180, http://dx.doi.org/10.1190/1.1440403.