The Application of Hierarchical Seismic Attribute Combination to High Precision Infill Well Planning in the South Tapti Field, Offshore Western India

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Summary

There was an urgent requirement in south Tapti field to get two in-fill wells in the shallow reservoir zones known as zone I and zone-II to maintain the falling production. Zone II has got three sands (II-A, II-B, and II-C) that are not resolved on seismic at many reservoir locations and hence manual mapping of seismic amplitudes was not effective. The key element of this study was to quickly delineate and map the zone II sands to help identify the in-fill locations. This was successfully achieved by adopting a methodology that involves identification and optimization of relevant seismic attributes and their hierarchy. Hierarchy itself is dependent on the stratigraphy of the target zone which, in this case is known to be fluvial distributary channels and tidal bars on a coastal plain. The selected/identified attributes were ranked and studied in three groups of hierarchical order- First, Second and Third order attributes First order attributes: were utilised to delineate the gross sand geometries of whole of zone II and comprised Total energy, Arc length, and Coherence; Second order attributes: helped to further segregate the sand geometries of zone II into sub-zones. Chosen attributes were Half time energy and Zero-crossings; Third order attributes: were then utilised to identify the reservoir scale features including connectivity and spatial distribution of the sands in the target zones. They were identified as Time Slices and Total negative amplitudes. The methodology was then applied in the South Tapti Field to identify two infill well locations which enable several stacked reservoir sands to be penetrated at each well location.

Introduction

The South Tapti Field is located in the entrance to the Bay of Cambay, approximately 160 km NNW of Mumbai, off the west coast of India (Fig. 1). The South Tapti Field is part of the Tapti Block Joint Venture (JV) Concession (ONGC, RIL and BG) and contains approximately 2 Tcf of GIIP in a four way dip closure anticline plunging to the south west.

The reservoirs in this field are of Oligo-Miocene age, and comprise a series of stacked tidal bar and distributary bchannel sands deposited during a period of late Oligocene regression and subsequent transgression during the early Miocene (Pandey, 1986). The late Oligocene Daman Formation is dominated by very clean, highly porous fluvial distributary channel sands that cut into an estuarine coastal plain that includes argillaceous tidal and mouth bar sands (Fig. 2). These are overlain by large estuarine tidal bar sands and sub-tidal channel sands, also extensively cut into estuarine mud background, but generally of lower quality and less clean sand. A total of 12 reservoir zones can be stacked vertically, each zone containing several sandstones. Currently, South Tapti Field gas is produced from the upper reservoir zones I to II. Zone I is predominantly sheet-like tidal bars, 5 to 18m in thickness whilst Zone II, separated from Zone I by a persistent 5m shale, comprises up to 4 stacked distributary sands, as documented by well data.

The stacking of reservoir sands, often with a thickness close to the limit of seismic resolution, together with wide variation in sandstone porosity and clay content, makes mapping of the sand bodies from conventional seismic amplitudes extremely difficult. The extent of the problem is

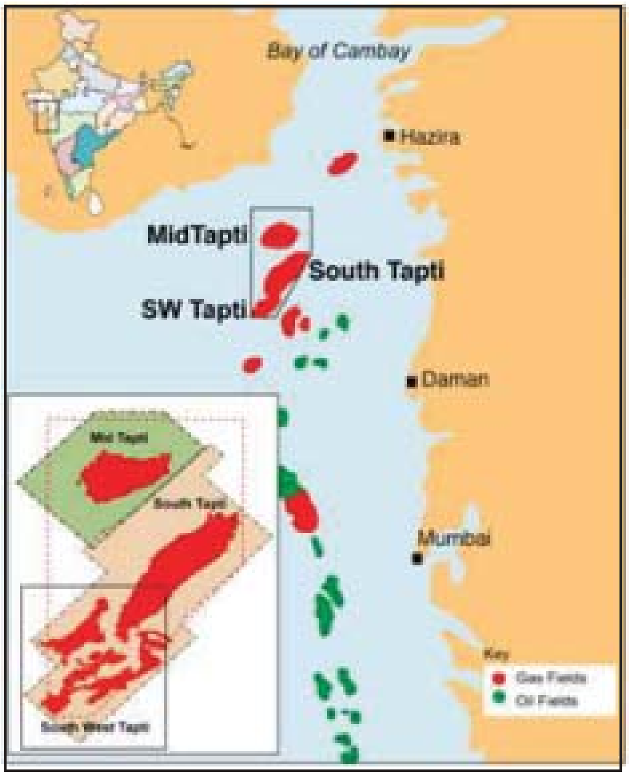

Fig. 1: Location of the South Tapti Field, offshore Western India, showing the extent of the seismic survey.

compounded because of variations in gas saturation in the sandstones, varying from as low as 20% to around 80%, and because of the presence of interbedded fully water-wet sandstones in the reservoir sequence. Consequently, conventional amplitude mapping of tidal bars is possible in the uppermost reservoir intervals, whilst only the most porous,

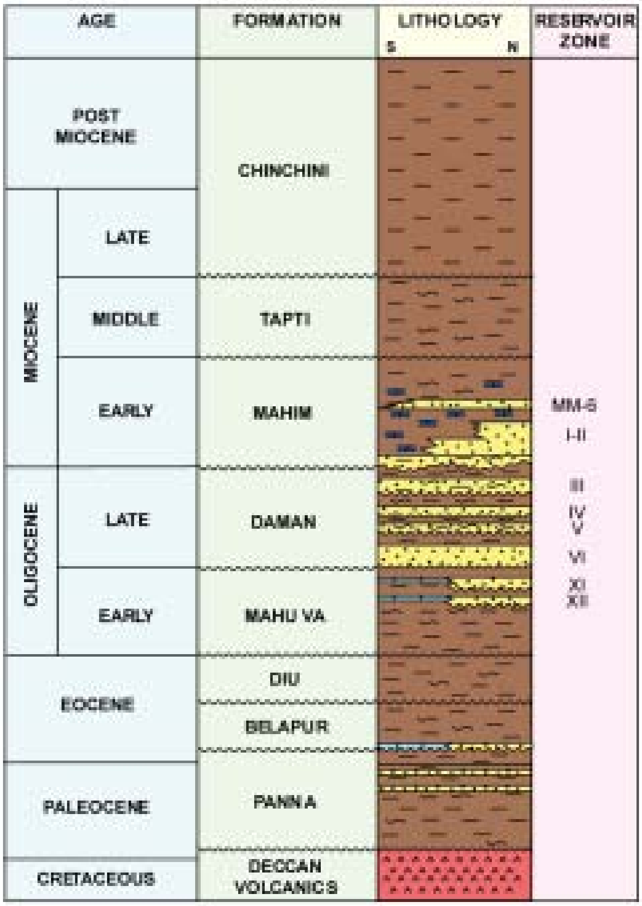

Fig.2: Summary stratigraphic column for the South Tapti Field, showing the main stacked reservoir zones.

thicker channel sandstones are revealed by amplitudes. Hence, many of the thinner sands within the upper reservoir zones are not revealed by manual mapping.

To improve delineation of reservoir sandstones other seismic attributes, in addition to amplitudes, were investigated and a methodology of ranking and optimizing combinations of attributes was developed that has enabled high precision planning of infill well locations on the South Tapti Field. We illustrate here how the technique was applied to Zone II reservoir delineation in particular. The broad objectives of the study were (i) to delineate the areas in Zone II where sands are present (ii) segregate/resolve these sands in terms of sub-zones II-A, II-B, and II-C and (iii) show the connectivity and spatial distribution of these sub-zone sands.

Methods

The main reservoir sands are not seismically resolved at many locations in the field and hence manual amplitude mapping in this field is ineffective at defining reservoir sands. The study was designed to extract amplitudes and seismic energy corresponding to the main reservoir sands both at the zone and sub-zone scale through the combination of hierarchical seismic attributes (Hart, 2002). The selection criterion of the seismic attributes was largely dependent on the stratigraphy of reservoir zones. In broad terms, attributes that help identify the presence of sands, delineate the channel geometries and help to resolve the extent of continuity and resolution were chosen (Chen and Sidney, 1997; Horkowitz, and Davis, 1996). The criteria used for each of these are discussed below:

- Identification of composite sands in zone II: Zone II is a shale-dominated package bounded by laterally extensive marine flooding surfaces. In this setting, seismic attributes that represent energy give an approximation of sand presence. Hence the ‘Total Energy’ and ‘Half-Time Energy’ attributes were tested by running the attribute algorithm with different parameters and were found to be effective in defining sand presence.

- **Delineation of sand geometries:** Keeping in view the stacking of multiple sands in Zone II (II-A, II-B, IIC), the chance of smearing of amplitudes due to interference and phase changes is real. Hence hybrid attributes such as ‘Arc Length’ and ‘Zero Crossings’ were tested to avoid these effects. In addition ‘Coherence’, which is independent of manual interpretation bias, proved very helpful in defining sand geometries.

- **Connectivity and spatial distribution of sands:** Finally, to look for connectivity and spatial distribution of sands, two attribute algorithms that were tested and found to be effective in defining sand connectivity and distribution were ‘Time slices’ and ‘sum of negative amplitudes’. The following attributes were effective in delineating sand parameters and were retained and optimised for use: Total Energy, Arc Length, Coherence, Half-Time Energy, Zero-Crossings Time Slice, and Sum of negative amplitudes.

Definition of hierarchy of seismic attributes

Once all the attributes were chosen and tested for their efficacy, they were ranked in three groups: First order, second order, and third order. Attribute ranking was based on the required objective at each stage of the study:

- Identification of sands in composite Zone II: First order attributes: Total Energy, Arc length, and Coherence
- Segregation of sands of Zone II into sub-zones II-A, IIB and II-C: Second order attributes: Half-time Energy and Zero crossings
- Connectivity and spatial distribution of the sub zones: Third order attributes: Time Slices and sum of negative amplitudes.

Extraction and analysis of seismic attributes First order attributes

Total Energy

Energy is the square of amplitude. The overall stratigraphic sequence in the South Tapti Field is shale dominated – essentially tidal bars and channel sands set in a background of estuarine shale - so greater reflection energy generally indicates the presence of more sand in a particular interval. Figure 3 shows the total energy extraction over the whole of the Zone II reservoir interval. Black indicates highest energy and is indicative of the presence of the thickest, massive sands in a background of shales and thin sands. Total energy reveals the areas of greatest sand development, indicating combined stacked channel geometries, although individual sub-zone sands cannot be distinguished with this attribute.

Arc Length

Arc Length is the total length of the seismic trace over a specific time window (Fig. 4). It is a hybrid attribute that combines components of amplitude and frequency, and is directly proportional to amplitude.

Arc length can be treated as a measure of reflectivity – with higher arc lengths representing better development of sand. Figure 5 shows the same area as Figure 4 as an Arc length extraction, revealing almost a similar image to Total Energy (longest Arc Length is shown in red) that indicates areas of thickest sand development.

Because Arc Length is independent of Total Energy, this attribute provides separate supporting evidence for the development of thick sand bodies with Zone II reservoir interval. However, as the attribute represents sand development over the whole of Zone II it does not provide geometrical information on sand bodies, but rather a composite picture of the zone.

Coherence

Coherence cubes calculated from 3D seismic provide a representation of the similarity (or dissimilarity) of the seismic waveforms and are therefore indicators of discontinuities in the seismic volume. Coherence is a measure of trace-to-trace similarity of the seismic waveform within a small analysis

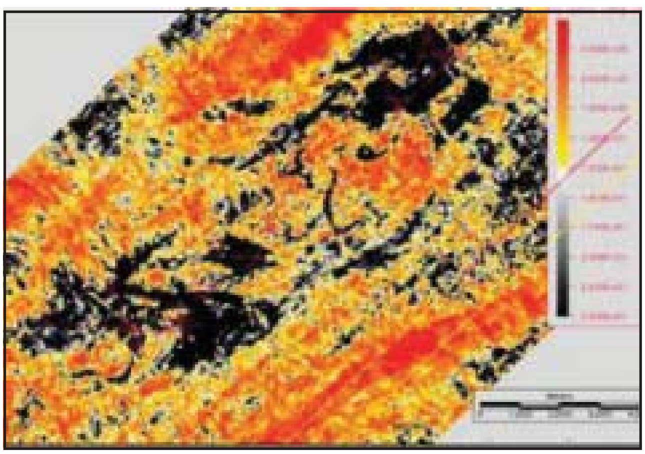

Fig. 3: Total energy extraction over the whole Zone II reservoir interval for the central part of the South Tapti Field, showing the maximum development of reservoir sand.

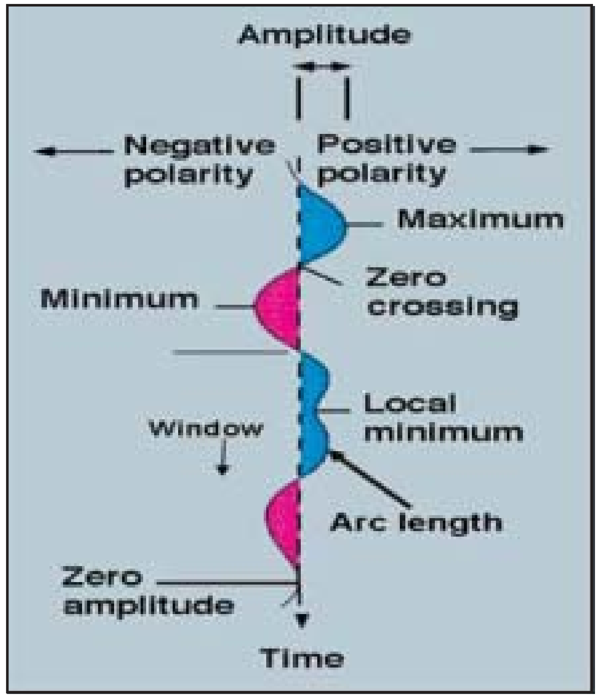

Fig. 4: Arc Length defined as the length of the seismic waveform over a given window.

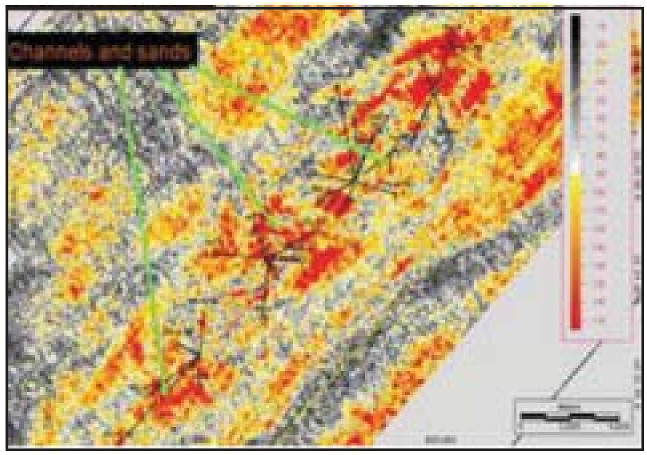

Fig. 5: Arc length extraction over the whole Zone II reservoir interval for the central part of the South Tapti Field, showing the presence of sands and channel geometries.

window. The algorithm involves a numeric process, which does not require any interpreted horizons, and so is free from interpretational bias. Coherence cube processing reveals shapes of subsurface reflectors such as structural features, pinch-outs, unconformities, channel boundaries and subtle sedimentological features that are difficult to interpret on reflection seismic volumes (Bahorich and Farmer, 1995).

A grey-scale coherence extraction covering the full window of Zone II is shown in Figure 6. White and grey areas represent areas of high coherency, whilst black areas represent features of low coherency, and thus discontinuities in the seismic data. Short, dark traces aligned NE to SW are small normal faults that cross-cut the reservoir, whilst the various sinuous elements that are clearly visible are discrete channels. These are delineated by their margins (where a change in dip is indicated); note that within the channels themselves the coherence volume displays a white colour indicating undisturbed bedding.

The coherence volume clearly indicates the presence of several discrete channels of high sinuosity within the volume of Zone II.

Second Order Attributes

These attributes were specifically chosen to further subdivide Zone II into separate channel systems. The attributes used were Energy half-time and Zero-crossings.

Energy Half time

Energy half-time first sums energy over the study interval starting from the top. The algorithm then sums again until half the previous total value is reached. If this point occurs above the mid point of the interval, the sands are located primarily towards the top of the reservoir. If this point occurs below the interval, the sands are located primarily towards the base of the reservoir. Energy half-time analysis of Zone II thus attempts to map the vertical distribution of sand within the reservoir interval.

Figure 7 is the Energy half time analysis of Zone II (scale in the figure is broadly equivalent to depth in the zone, with red being shallowest and black being deepest in the zone). Note that the clear channels resolved in the coherence volume are displayed as grey bodies with this attribute, indicating that they occur in the lower part of the zone. This attribute helped to achieve three levels of vertical zonation as is shown in the Figure 7. Light grey to black colours clearly represent the channel geometry of deepest sub-zone II-C. Zone II-A and II-B are represented by red to white colours on the map

Number of Zero-crossings

The number of zero crossings mapped over an area

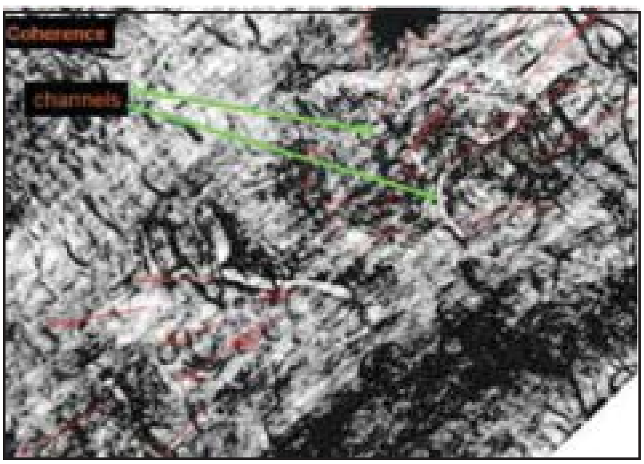

Fig.6: Coherency extraction over the whole Zone II reservoir interval for the central part of the South Tapti Field, projected onto an horizon slice, showing detail of Zone II the channel geometries.

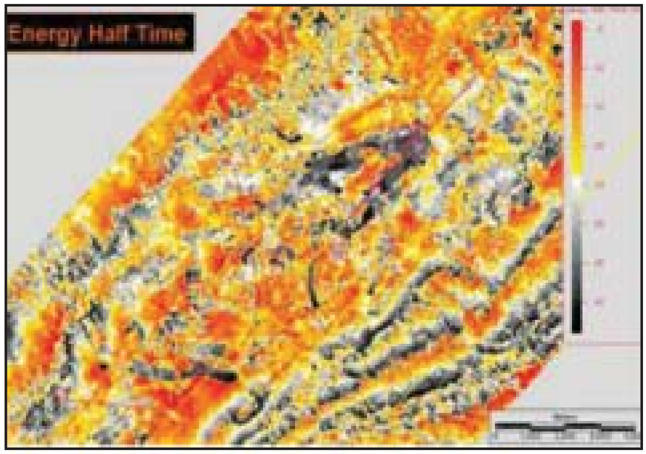

Fig.7: Energy half-time analysis over the whole Zone II reservoir interval for the central part of the South Tapti Field, indicating the distribution of the sands within Zone II.

provides an indication of layering within the area. The greater the number of zero crossings the greater the degree of shale interbedding within the formation. Zero-crossing attribute is expected to give sand resolution within seismic resolution limit of the order of 8-10 m. This attribute was used to corroborate and calibrate the deductions from the 'Energy half-time' attribute extraction. Figure 8 is a zero crossings attribute extraction of the same area of the South Tapti Field as shown in Figure 7 and illustrates presence of sub zones II-A, II-B and II-C in areas with higher number of zero crossings. Dark brown colours show areas of more zero crossings and hence are likely to be indicative of areas where all the sub-zone sands are present.

Together, these second order attributes helped segregate and delineate individual sands within Zone II of the South Tapti Field. They provide much more resolution of individual sands than the first order attributes and thus complement them in resolving sand distribution.

Third order attributes

Third order attributes were utilised to identify the

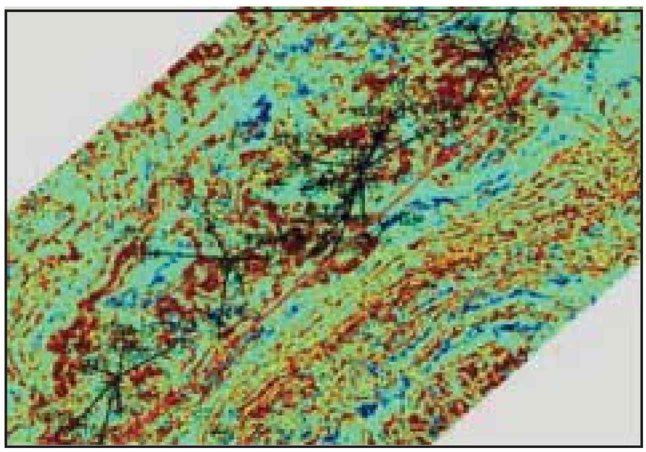

Fig.8: Number of zero crossings attribute analysis over the whole Zone II reservoir interval for the central part of the South Tapti Field, indicating the extent of shale interbedding within Zone II.

detailed reservoir level features specifically such as connectivity of sand bodies and the spatial distribution of the sands within the target zones. The attributes identified as being particularly useful were 'Time Slices' and 'Total negative amplitudes'.

Time Slices

Time slices cut across the seismic volume to reveal the continuity of these sands at the level of the time of these slices. Time slices being frequency and structure (dip) dependent, due care was taken to understand the 3D relationships of the amplitudes. Time slices were taken every 4ms through the Zone II volume to establish the extent of connectivity in sand bodies and map out their spatial distribution.

Figure 9 is a composite of 4 time slices that successively represent deeper layers within Zone II. Yellow color at every level shows the extent/connectivity of the sands.

Sum of Negative Amplitudes

Amplitude maps were finally prepared with the help of time slice summations taking help of first and second order attributes as well. Channels and sands in zone II-C are clearly delineated as shown in Figure 10.

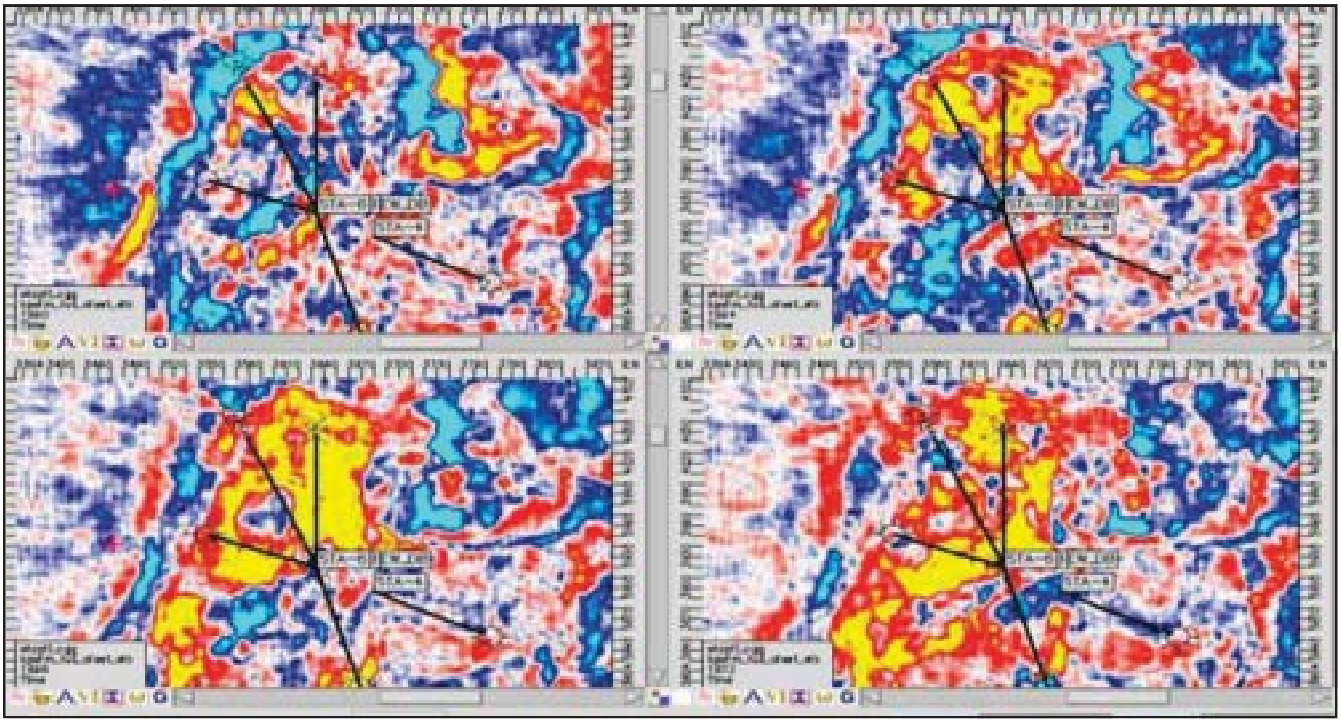

Fig. 9: Four successive time slices in the zone of interest

Conclusions

In many areas amplitudes are not effective (unreliable) to delineate many of the thinner sands either due to resolution or other issues like interference, phase problems and noise in the data. The hierarchical study of relevant seismic attributes can be utilized as an effective alternative in such situations. Hierarchy and selection of attributes is itself dependent on the expected stratigraphy of the target area/zones.

The study specifically addressed the need to drill two infill wells to arrest the current decline in field deliverability. In the infill well campaign, the primary targets are focused mainly in the upper reservoirs as all of current field production is coming from it .The infills were meant to be targeted in the upper reservoirs (Fig-2) where zones II-A, II-B and II-C are not seismically resolvable at many reservoir level locations and hence manual mapping of the amplitudes was not effective. To meet the objective under the challenging situation, the hierarchical 3D seismic attribute study was taken up and it is proved to be the most robust technical driver in finding the infill locations.

In south Tapti, this approach helped to define better channel geometries and map(delineate) additional sands in sub zones II-A, II-B and II-C. The study was the key to find the two in-fill locations at places/zones (sub zones II-A) which were earlier thought to be shale sequences. One of these in-fills, has already been drilled with an approx. net pay of 12 m.

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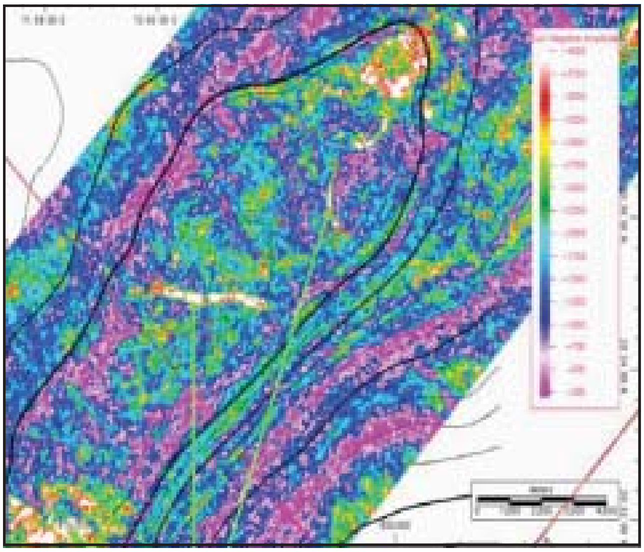

Fig.10: Sum of negative amplitudes map over the whole Zone II-C reservoir interval for the central part of the South Tapti Field, indicating the distribution of the sands within Zone II. Pink to yellow colour sacle represent the increasing negative amplitudes.

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