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Impacts of thin hard streaks of Tipam sandstone reservoirs on 3-D seismic attributes: Modelling guided interpretation of log and seismic data in Changmaigaon area of Upper Assam Shelf, India

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Summary

In the Changmaigaon area of Upper Assam Shelf, Tipam sandstone of Miocene age is main oil bearing reservoir. The sandstones are massive in nature and were deposited by fluvial processes of braided and meandering rivers in continental environments. The fluvial depositional cycles of 10 to 20 m thickness are separated by thin shale bands and within cycles thin hard streaks of 1 to 2 m thickness and of variable composition occur intermittently. The thin hard streaks have very high velocity and density and due to this impedance contrasts between hard streaks and sands or shales are very high. The seismic response is composite of reflections from sands, thin shales and thin hard streaks and other non lithological changes such as fluid saturation. The subtle variations in reflections which may be caused by saturating fluids are often masked by lithological changes, mostly by hard streaks because of very high acoustic properties. Seismic attributes derived from composite reflections of 3-D seismic and reservoir properties estimated from well logs do not explain all the dry and oil wells. The reservoir properties (reservoir facies, porosity) are found in acceptable range for both dry and oil wells. The fault based structural models do not explain some of the dry wells located at favourable positions.

Thin hard streaks are important in modifying the overall seismic and log responses. Through this paper, an attempt has been made to assess the impact of thin hard streaks on seismic attributes by analysing log and seismic signatures and correlating them by means of synthetic modelling. Hard streaks are not favourable from reservoir properties point of view but their abundances are observed to be associated with oil wells. The net effects of hard streaks are to enhance the amplitude and continuity of reflections and increase the mapability within massive sands which may be otherwise "reflection free".

Introduction

Seismic attributes depend on the acoustic properties of subsurface rocks and properties depend on depositional environments and processes. Depending upon components of basic seismic data, attributes can be divided into two categories, derived from morphological components and derived from reflectivity component. Morphological attributes give information on reflector time, dip, azimuth, termination etc. which may be related to faults channel etc. and attributes based on reflectivity provide stratigraphic and reservoir information such as lithologic variations, reservoir thicknesses, and presence of hydrocarbon (Direct Hydrocarbon Indicators DHI). Effectiveness of attributes depends upon subsurface rock properties and it may vary from area to area depending upon geologic complexities. Background geologic information may enhance the chances of interpretation close to the reality. This study is related to application of 3-D seismic attributes for delineation of Miocene Tipam pay sands in Changmaigaon field of Upper Assam shelf, Assam and Assam-Arakan Basin, India. In the basin application of 3-D seismic started in late 1980's.

Structural mapping and identifications of stratigraphic features (channels, bars) are successful but predicting the hydrocarbon bearing layers, even with good well control, is limited. In the area, Tipam sandstones are geologically complex due to presence of intercalated thin hard streaks/layers and thin shale bands. The geologic complexities influencing the seismic and log responses were examined through evaluation of logs and 3-D seismic data. The reservoir properties derived from logs are almost similar in the

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area. The ratio of cumulative thickness of hard streaks to gross thickness is corroborated, qualitatively, with occurrence of oil wells. Synthetic modelling and correlation between abundance of streaks and seismic amplitude have shown that seismic attributes are greatly affected by intercalated thin hard streaks/layers.

Geologic Overview

The Changmaigaon area is located in the west-central part of the Upper Assam Shelf (Figure 1) and is under both exploration and development stage since 1984. The Upper Assam shelf is a part of Assam-Arakan Basin which is a shelf–slope–basinal system. Evolution of Basin and depositional environments and processes are deliberated by number of authors from time to time (Bhandari et al., 1973; Mathur and Evans, 1964; Raju, 1968). The stratigraphic succession ranges from Pre-Cambrian Granitic basement to the Plio-Pleistocene Namsang Formation, with intervening Jaintias of Palaeocene and Barails of Oligocene and Tipams of Mio-Pliocene age (Figure 2). Oil bearing sands in this field are restricted to the Tipam sandstone of Miocene age. In the area a total of 25 wells have been drilled out of which six exploratory and three development wells are dry. Few dry wells are located at structurally favourable levels within envisaged oil-water contact limit.

Fluvial sequence stratigraphy of Tipam sandstones

Tipam sandstones unconformably overlie Oligocene Barail Formation and underlain by Girujan shales (Figure 2). The Upper part of Barial Formation, Barail-coal shale (BCS) unit, consists of coals, shales, and discontinuous sandstones deposited in a delta-plain environment. After deposition of BCS there were prolonged upliftment and erosion caused by crustal shortening during Upper Oligocene (top of Rupelian, 28.5 Ma) to lower part of Lower Miocene (Acquitanian, 20.52 Ma) (Chandra et al. 2001). Tipam sandstone were deposited in continental condition by fluvial processes away from marine influence though its coeval part, Sumra Group, is deposited under-fluvial deltaic to estuarine condition in the south-western part of Assam Geologic province. In sequence stratigraphic concepts, isolated fluvial sequences away from coeval shorelines and marine influences are formed during low accommodation and high accommodations instead of lowstand, transgressive and highstand (O. Catuneanu, 2008). The stratigraphic cyclicity of fluvial deposits may be driven by tectonic cycles superimposed on a long term climatic background. Low and high accommodation system tracts in fluvial depositional sequence alternate within a vertical succession depending upon accommodation setting.

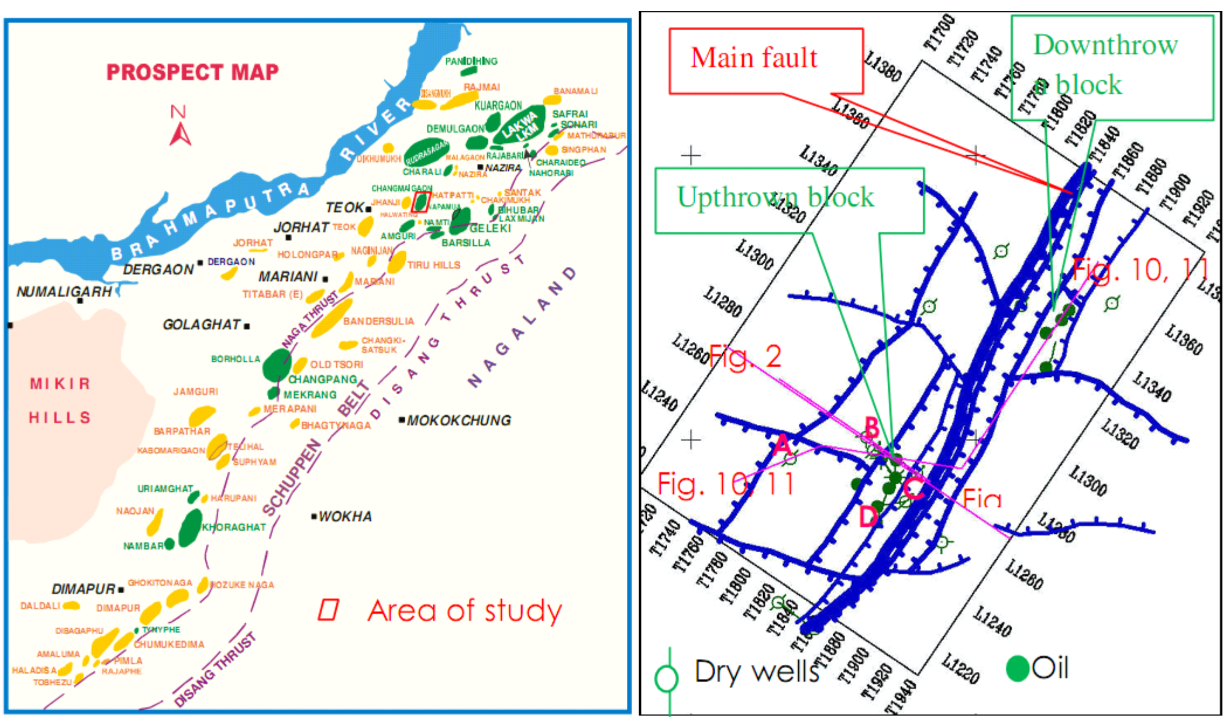


Figure 1. (A) Map of Upper Assam shelf showing area of study. (B). Basemap of 3-D showing major faults and drilled wells.

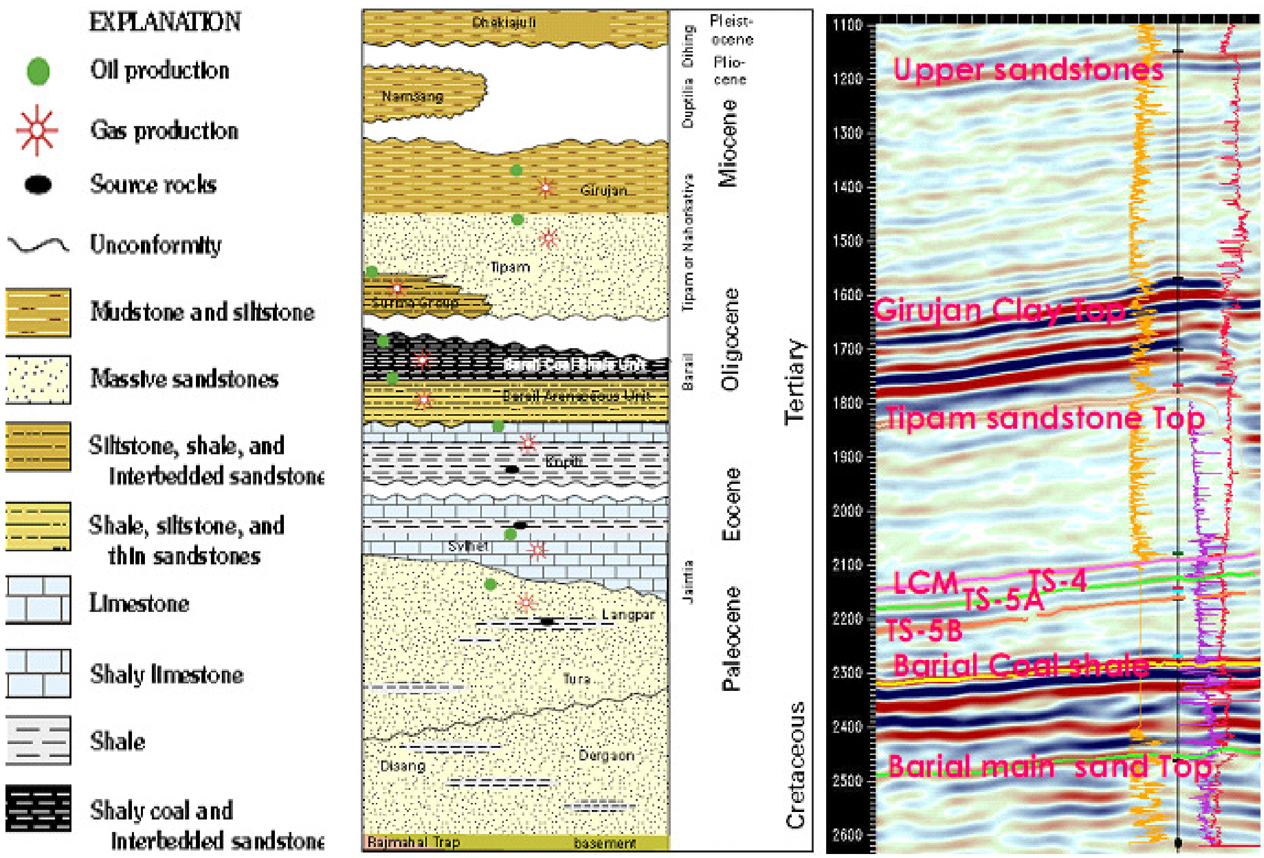


Figure 2. Generalised stratigraphy of Upper Assam Shelf and typical seismic and log signatures of BCS unit of Barial Group, Tipam

The typical log motifs of Tipam sandstone within 100 m vertical succession (Figure 3) show cyclic coarsening upward trend at base followed by fining upward trend. Hard streaks and thin clay bands are embedded within sands. The fining upward trend is related to gradual decrease in topographic slope during orogenic loading that is caused by pattern of differential subsidence. Lowering in slope gradients changes the fluvial styles, from initial higher to final lower energy systems, i.e., braided to meandering systems. Thus Tipam sandstones are product of vertical and lateral coalescence braided channels and point bars of meandering streams. We are getting, mostly, fining upward cycles because high accommodation sediments (fining upward) are better preserved (O. Catuneanu, 2008).

Log and seismic signature of pay sands and hard streaks

In the area, Tipam sandstones are divided into six sands. Bottom pay sands, TS-6, TS-5, and TS-4, are separated from overlying pay sands TS-3, TS-2 and TS-1 by a very persistent Lower Clay Marker (LCM). The TS-5 is further subdivided into TS5A, TS-5B and TS-5C. The upper part of TS-5A sands is oil bearing. Testing results and log evaluations have indicated oil in other sands also (TS-6), TS-4, TS-2 and TS1). The log correlation profile showing GR, LLD, NPHI, RHOB, AI and DT logs between TS-5A and TS-5B intervals and passing through dry and oil wells is shown in Figure 4. TS-5A sands are bounded by thin shales at top and bottom.

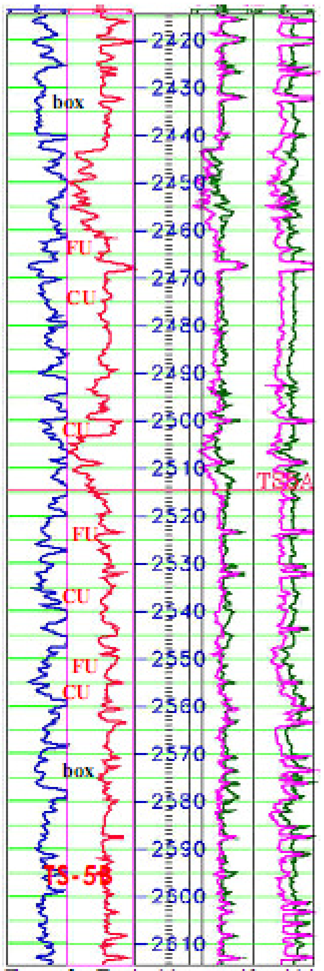


Figure 3. Typical log motifs within 100 m succession of Tipam sandstones. (FU: fining upward, CU coarsening upward).

Within interval individual depositional cycles are about 10 to 20 m thick. Hard steaks are very prominent on DT, RHOB, NPHI, and computed impedance (AI) logs and are mostly located in low GR zones (sandy intervals). Generally oil and water sands are not distinguishable from resistivity values. The gross thickness of TS-5A sand, cumulative thickness of hard streaks and ratio of cumulative thickness to gross thickness within the interval are shown in Figure 5. The cumulative thickness of hard streaks shows NE-SW trend in the area.

On vertical sections (Figure 2), zones of parallel and continuous high amplitude events, parallel and medium amplitude events and very low amplitude events are seen. High amplitudes belong to coal-shale and clay-silt alternations of BCS and Girujan Clay formations. Medium amplitudes represent band of LCM, TS-4, and-Top of TS-5. Very weak amplitudes correspond to massive sandstones. Variable amplitude and poor continuity is standard response of non-marine sediments. Reflection events are composite in nature because of low frequency (30 Hz) thin fluvial depositional cycles of less than 25 m are not resolved at interval velocity of about 3000 m/s. The natures of onsets (peak, trough or zero crossing) of pay top reflectors are uncertain due to interferences from thin layers. The composite reflection may encompass sands, shale and hard streaks (Figure 4). Impacts of thin hard streak (1-2 m) on the composite response cannot be inferred directly.

Impedance characteristics of hard streaks

Impedances of layers are analyzed through crossplots between lithology (GR) and Impedance (AI) (Figure 6A) and between velocity and density (Figure 6B). Sands have lower impedance than thin shales and hard streaks. Impedance of hard streaks (10505 m/s*g/cc, Table 1) is very high than shale (7968) and normal sands (6958). Hard streaks are concentrated, mainly, in sand intervals. GR-AI crossplot shows three trends: i. Background-impedance increases with increase in GR, ii. Hard streaks in sands- impedance increasing with decrease in GR, iii. Hard streaks in shales- high impedance and high GR. The effects of hard streaks on impedance is to increase the impedance of gross sands and to decrease the impedance contrast between gross sands and shales (Table 1).

Reflection characteristics of hard streaks

To examining the effects of thin streaks on the reflection response, three sets of synthetics (Figure 7) were generated using sonic and density logs and 30 Hz Ricker wavelet. In first set (Figure 7A) original logs were used and in second set (Figure 7B) streaks were smoothed on sonic and density logs. Reflectivity and reflection amplitude decreased significantly after removing the thin streaks. The model response shows that thin streaks (1 to 2 m) are main controlling factor of the seismic amplitude. The third set (Figure 7C) is response from only hard streaks by smoothing the impedances of other lithologies. It also shows appreciable amplitude indicating that thin hard streaks are responding at normal seismic frequencies (30-40 Hz). Amplitude in A is sum of amplitude of B and C. Subtle changes due to fluids (oil and brine) are masked by these lithologcal variations and are not detected by seismic attributes.

Structural Model and reservoir property maps

The structure map of top of TS-5A pay sand is shown in Figure 8. The field is divided into two blocks located towards upthrown and downthrown sides of a prominent NNE-SSW trending fault. These blocks are further intersected by a number of parallel faults. Subsequent shearing movement across these earlier faults along with reactivation and inversion due to later tectonics have formed some fault related closures where hydrocarbons have been preserved and at the same time escaped in some other blocks although having the same structural level and reservoir facies.

Reservoir property maps derived from log data show that facies and properties are not deciding the dry or oil wells. Porosity map (Figure 9) shows that some dry wells are falling in high porosity zones. It means that all sand of the area can accumulate the hydrocarbon provided migration path and trap is available.

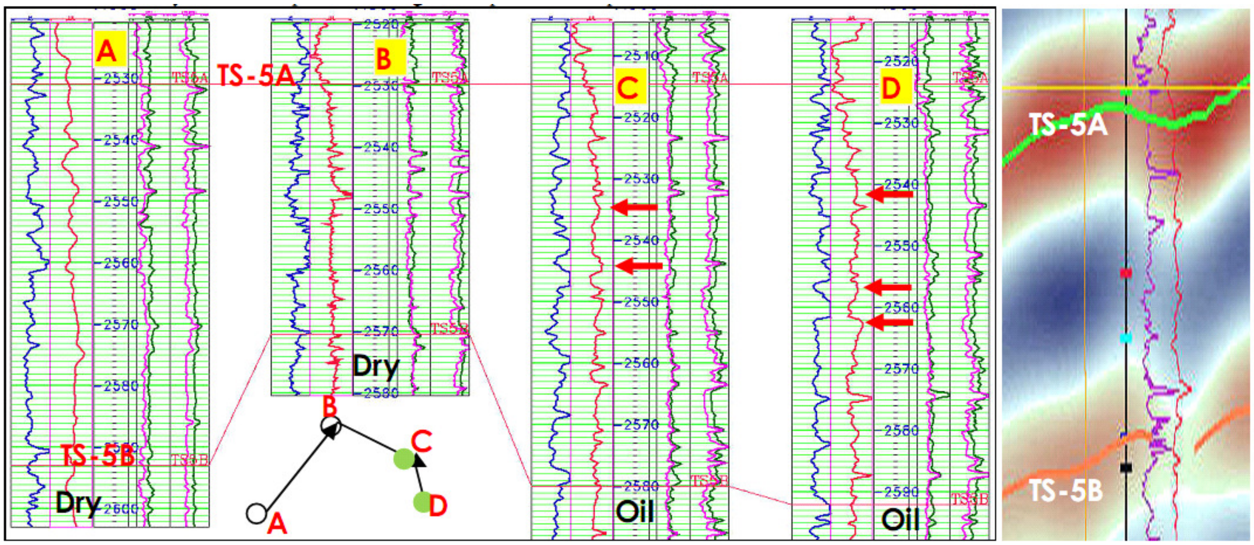


Figure 4. Log and seismic signatures of TS-5A sands in Changmaigaon area. Log profile is flattened at TS-5A top. Well -A and B are dry and C and D are oil wells. Tested oil zones are marked by red arrows. Thin hard streaks are evidently seen from high velocity, high density and almost zero Neutron porosity (NPHI). Hard streaks sometimes located at the base of fining upward cycle. A single composite seismic event encompasses all the reflections from sands, shales and hard streaks.

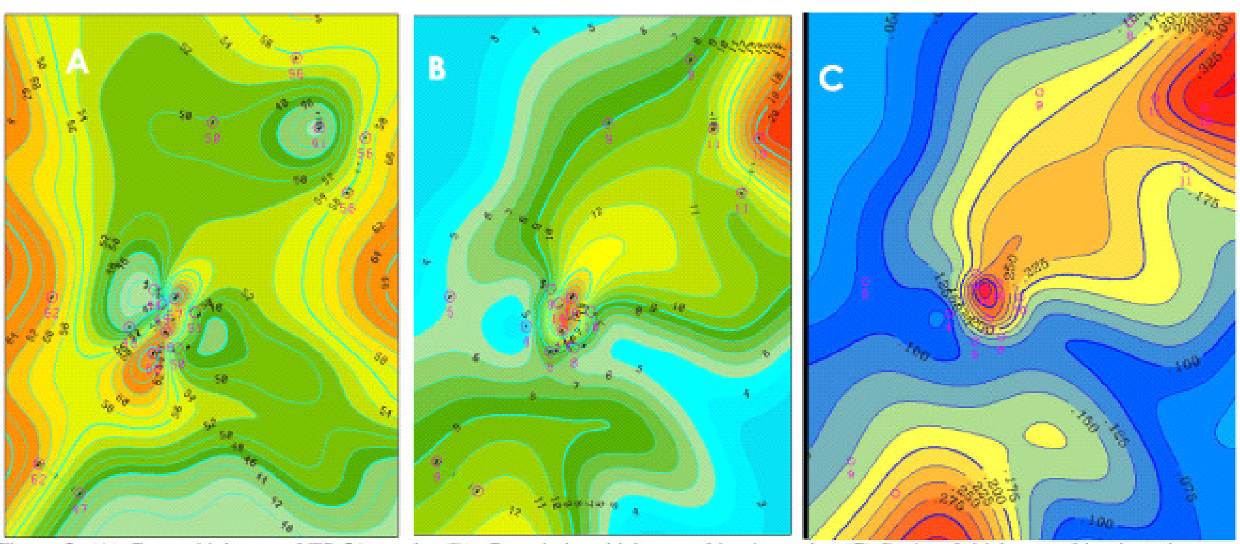


Figure 5. (A) Gross thickness of TS-5A sands, (B), Cumulative thickness of hard streaks, (C) Ratio of thickness of hard steaks to gross thickness. Index: Red-high, Green-Medium, Blue-low.

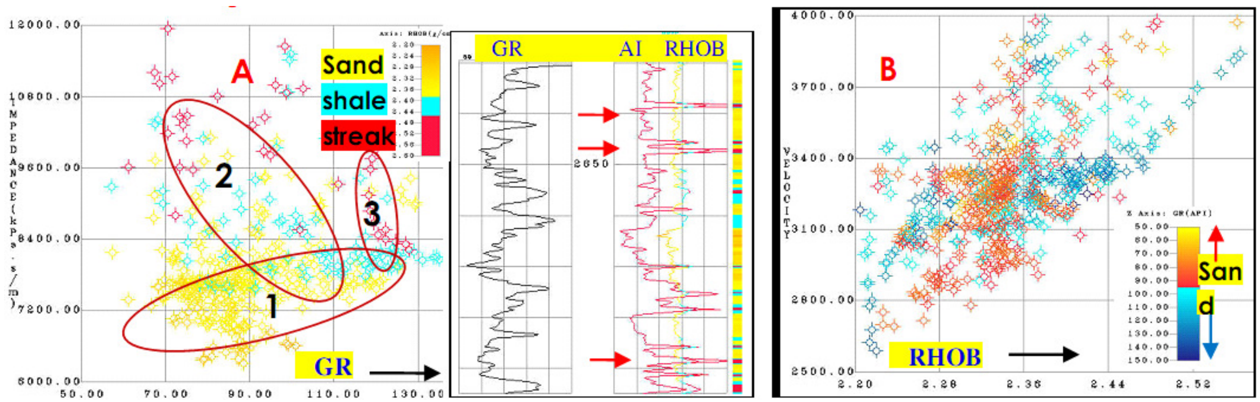


Figure 6. Crossplots between Impedance and GR logs (A) and between Velocity and Density logs (B). In (A) colour coding is with respect to density values and in (B) colour coding is with reference to GR log. Hard streaks are present in both sandstones and shales but occurrences in sandstones are greater than in shales. AI-GR crossplot shows three trends: 1. Background, 2. hard streaks with low GR 3. hard streaks with high GR. Some of hard streaks are marked by red arrows.

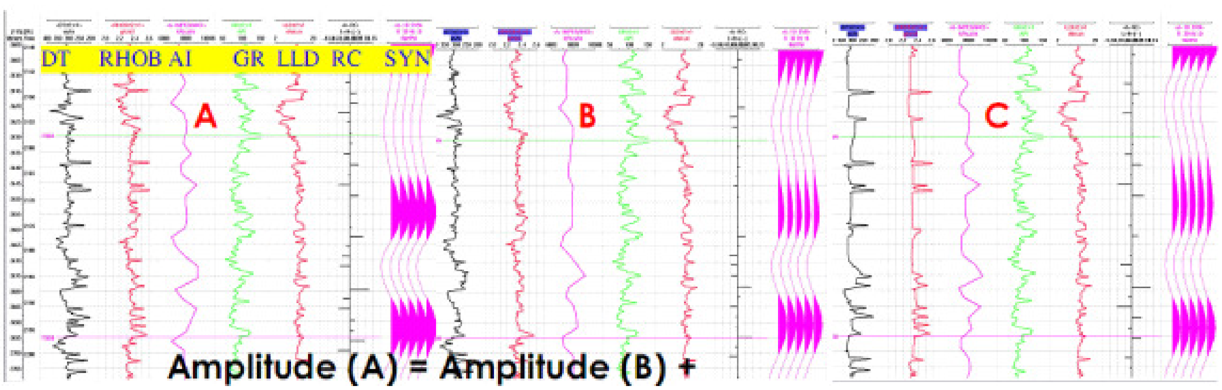
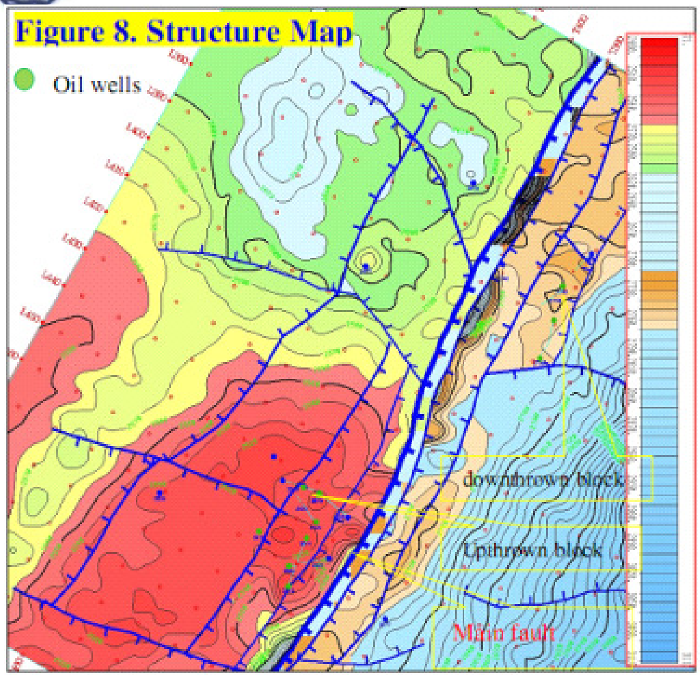


Figure 7. Synthetic seismograms generated from original (A) and smoothing streaks (B) and keeping streaks only (C). Reflectivity and reflection amplitude of composite events decrease after smoothing the thin high velocity and high density streaks in DT and RHOB logs.



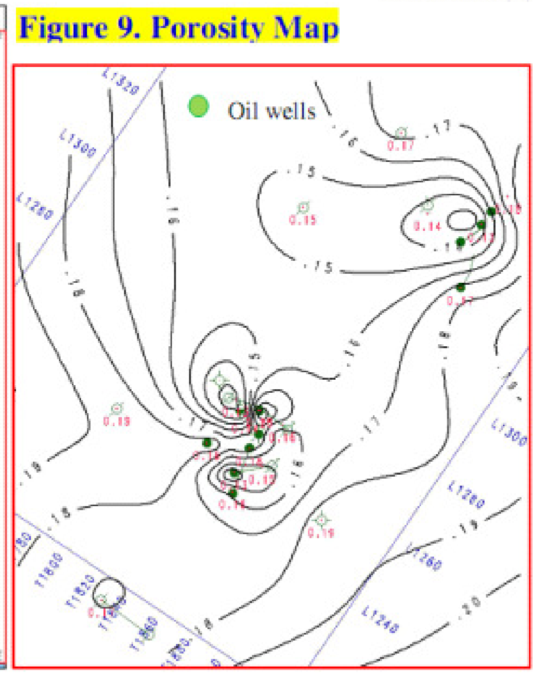


Figure 8. Structure map of TS-5A pay sand top. Oil wells are located in narrow fault blocks in both hanging wall and foot wall side of main fault. Large terrace towards west has no success. Figure 9. Average porosity map of TS5A. Porosity is varying from 13 to 19 % and oil wells are relatively in low porosity zones. Porosity is not a critical parameter for H/C accumulation in this field.

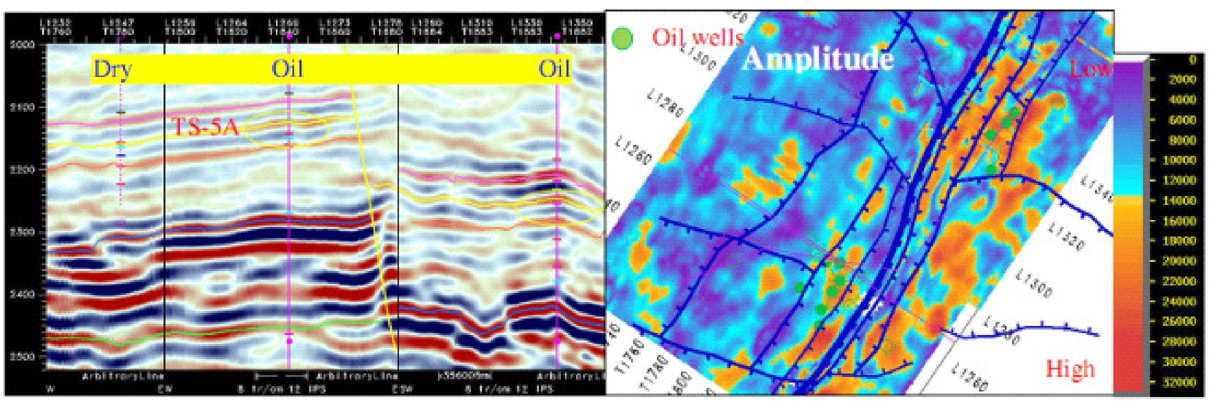


Figure 10. (A) Seismic section passing through dry and oil wells and spanning over upthrown and downthrown side of main fault. (B).Amplitude horizon slice of TS-5A top.

Table 1. Impedance of different components in the composite reflection					
Lithology	Gross 100 m	10 m sand	Shale	Hard streaks	Gross sands with streaks
Velocity (m/s)	3350	3050	3320	4300	3600
Density (g/cc)	2.348	2.28	2.4	2.443	2.396
Impedance (m/s*g/cc)	7865	6958	7968	10505	8625

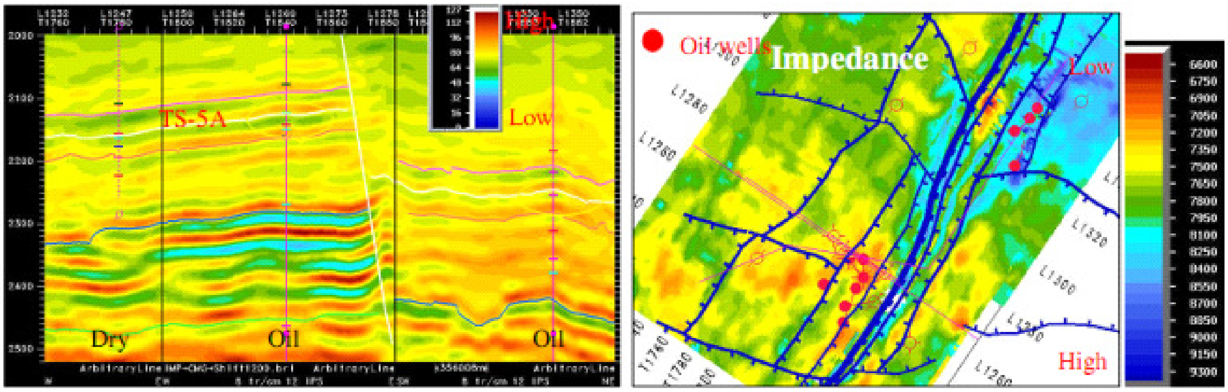


Figure 11. (A) Impedance section passing through dry and oil wells and spanning over upthrown and downthrown side of main fault. (B). Impedance horizon slice of TS-5A top.

3-D seismic attributes and Acoustic Impedance

Various seismic attributes were computed along the pay top reflector (horizon slices) and in the interval containing the oil pay zone. A seismic section and amplitude horizon slice are shown in Figure 10. Qualitatively, oil-wells are situated in relatively higher amplitude area. Post-stack acoustic impedance volume was generated by combining well and seismic data. An impedance section and impedance horizon slice is shown in Figure 11. Impedance is divided into three zones: low medium and high. The wells falling in high impedance zones are dry in main southern block of filed. Low to medium impedance zones are oil bearing. In the northern block impedance is high compared to southern block.

Results and discussion

Log interpretations supported by available literature show that hard streak within Tipam sandstones were deposited in nonmarine environments by fluvial processes of braided and meandering rivers. The log motifs (cyclic coarsening and fining upward etc.) of Tipam sandstone are explained through Fluvial Sequence Stratigraphic Concepts (O. Catuneanu, 2008). Due to very high impedance contrasts, thin streaks (about $\lambda/30$) are visibile at normal wavelengths (λ=100 m (A. R. Brown, 2004). In our case λ is about 100 m at velocity 3000/m/s and dominant frequency 30-40 Hz. Ratio of thickness of hard streaks to gross thickness (Figure 5) has good corroboration with oil bearing wells. Wells falling in low ratio zones are generally dry. Synthetic modelling has shown that amplitude of seismic events is increased due to hard streaks (Figure 7). Seismic amplitude is normally corroborating with distribution of hard streaks (greater the numbers of streaks per unit thickness, greater the amplitude).

Conclusions

Very high impedance properties of thin hard streaks make them visible at normal wavelengths (λ= 100 m) of seismic signal. Hard streaks increase the amplitude and continuity of composite seismic events and thus enhancing the mapability from seismic data. The subtle variations in amplitude which may be caused by saturating fluids are often masked by thin streaks. The abundance of streaks (ratio of thickness of streaks to gross thickness) has good corroboration with distribution of oil bearing wells. Relatively high amplitude, low impedance and high thickness ratio of hard streaks are in good corroboration and when integrated they may define the oil zones. Mapping of hard streaks may be an additional method for identification of hydrocarbon bearing zones in similar fluvial deposition systems.

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