Characterizing Triassic Sands from Seismic Attributes: A case study from Mandapeta Field, KG Basin, India

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Abstract

Mandapeta field is one of the most complex gas fields in KG onland. Hydrocarbon prospectivity of Gondwana sediments have been established for the very first time in India in this field in 1988 with the discovery of Well-1. After this breakthrough rigorous G&G studies have been conducted and a large number of exploratory and development wells have been drilled to explore and exploit hydrocarbon from this area. Exploring Mandapeta Formation has always been a challenging task as these sediments had undergone multi-phase of tectonics. Mandapeta sands are essentially part of braided channel system having vertical as well as lateral heterogeneity. Hence it becomes imperative to classify the sand characteristics to decipher the reservoir properties. Horizon based seismic attributes have been extracted to characterize sands within Mandapeta Formation. In this study, reflection strength, instantaneous frequency, RMS amplitudes & sweetness attributes are generated and analysed in detail. The amplitude attributes depicted the amplitude anomaly which may or may not correspond to hydrocarbon bearing zones. However, sweetness attribute acted as a de-risking tool in mimicking the accurate hydrocarbon distribution of the reservoir which preserves both amplitude and frequency content of the seismic data. This sweetness attribute is one of the best available tools to highlight the sweet locales to identify hydrocarbon bearing sand. This attribute studies further aided significantly in finding more prospective areas which will facilitate in exploring/exploiting more hydrocarbons from this field.

Introduction

In any interpretation project, basic objective is to understand the subsurface geology and hydrocarbon habitat of the field. Basic interpretation workflow comprises of marking major markers in well logs, map those markers in seismic, prepare structure maps and finding structurally favorable areas for exploiting hydrocarbon. However, this basic workflow is not enough to characterize reservoir in complex geological setup. Previously, Mandapeta field has been explored and developed based on structure maps. Reserves are estimated and revised with drilling of new wells and new findings. Seismic data quality was poor to map Mandapeta top, so analyzing attributes in this area has always been challenging task to address the reservoir heterogeneity. Long-offset seismic data was acquired to capture true subsurface image. This newly acquired data has good to fair seismic continuity at Mandapeta Formation and deeper levels. A detailed seismic interpretation was carried out in this newly acquired data by application of attribute extraction to quantify the seismic characteristics of the interest.

Seismic attributes are primary tools for describing subsurface geological feature. It has been widely used in the industry for 60-70 years for detection of hydrocarbon reservoirs. With the advancements in technology, many new attributes have been introduced, however, all these attributes represent the fundamental properties of a seismic trace or wavelet i.e. amplitude, phase, frequency etc with certain arithmetic operations. Seismic attributes aided in finding hidden information in the data which cannot be derived from standard seismic interpretation. In this study an attempt has been made to characterize Madapeta pay sands through various seismic attribute analyses, thereby understanding the heterogeneity in reservoir sands and utilizing these seismic attributes as direct hydrocarbon indicators.

Geology of the study area

Tectonic setting

The Krishna Godavari Basin is a peri-cratonic passive margin basin comprising of a number of North East – South West trending Horsts and Graben structures. The basin has a polycyclic (dual rift) evolution history in the eastern continental margin of Indian Plate. Continental stretching under northwest-southeast extensional forces initiated rifting along the northeast-southwest strike of primeval structural grain (Eastern Ghat Orogeny) during late Jurassic - early Cretaceous period. The younger Krishna-Godavari structural trend is superimposed over the earlier intra-cratonic rift set up of Pranhita-Godavari Graben, thus exhibiting typical poly basinal tectono-sedimentary assemblages. The basin experienced a major hiatus of magnitude around 65 Ma from late Triassic to late Jurassic prior to the breakup of the Indo-Australo-Antartica Gondwanaland. Major tectonic elements of KG-PG Basin are shown in Fig.1. Tectonically, the Basin can be divided into three sub basins, namely the Krishna, West Godavari and East Godavari Sub Basins which are separated by the Bapatla and Tanuku Horsts respectively. The West Godavari Sub basin is further separated by Kaza – Kaikalur Horst into the Bantumilli Graben and Gudivada Graben. Two major cross trends, Chintalapalli and the Pithapuram cross-trends define the intracratonic Pranhita-Godavari Basin. The study area encompasses two major NE-SW trending Horsts – The Tanuku Horst to the North and Poduru - Yanam/ Draksharama - Endamuru High to the south which plunges southwardly. The NE-SW trending axial low present in the area is bounded by Poduru- Yanam/ Draksharama - Endamuru High to the South and Tanuku Horst to the North referred to as Mandapeta low in the Mandapeta area. The NE-SW basement faults and the NW-SE cross faults define the Horst and Graben geometry of the basin. Endamuru Field is situated in this tectonic set-upon a basement high. The Matsyapuri-Palakollu fault system present in the southern flank of the Poduru - Yanam/ Draksharama - Endamuru High, confines Tertiary Plays to the south of it.

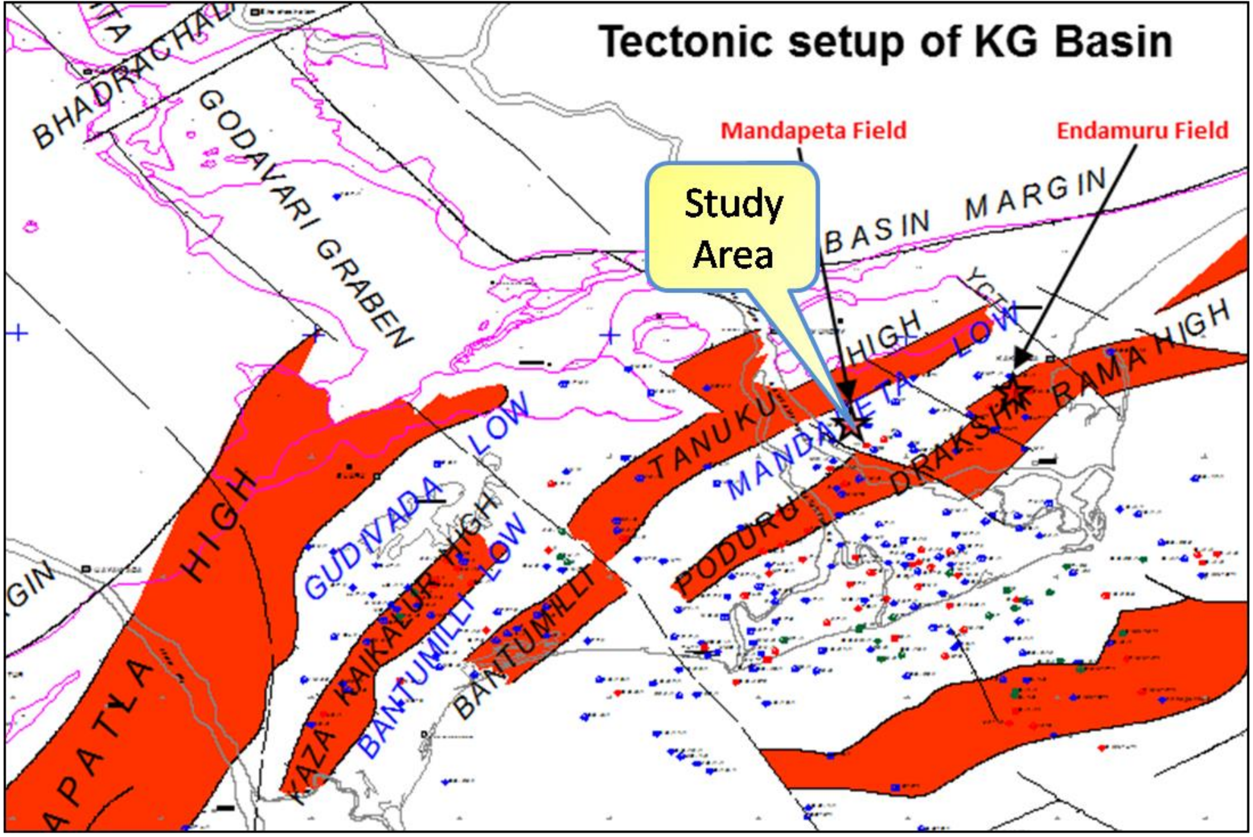

Fig.1: Tectonic element of KG-PG basin and study area.

Generalized stratigraphy and Depositional regime

The depositional environment of KG-PG Basin is controlled by a series of rifting phases. The oldest rocks encountered are the Pre-Cambrian metamorphic rocks consisting of Gneiss and Quartzite. These are overlain by boulder beds (Talchir Boulder Bed) which are basement derivatives and Argillites which are deposited in localised small intra-cratonic grabens. The full-fledge deposition of sediments over Basement in this part of Basin was initiated during Permian and was terminated with the break-up of the Indian land mass from Gondwanaland during Jurassic. The oldest sedimentary section, called Kommugudem Formation of early Permian rests on the crystalline basement. It is dominantly a coal shale sequence with subordinate sands deposited in a fluvio–lacustrine environment which marks the initiation of Gondwana sedimentation during Permian time. After a period of non deposition, a lower delta plain setting to an upper delta meandering fluvial deposits and finally a braided fluvial regime prevailed during late Permian to early Triassic time and resulted in the deposition of Mandapeta Formation. The basin experienced a major hiatus of magnitude around 65 Ma from late Triassic to late Jurassic prior to the breakup of the Indo-Australia-Antartica Gondwanaland. Red Bed Formation deposited over the Mandapeta Formation. Red Bed is a reddish brown to chocolate brown ferruginous sequence which is dominantly argillaceous in nature with alternating sandstone. This was followed by the deposition of Golapalli Formation of late Jurassic to early Cretaceous in the axial lows oriented in NE-SW direction, perhaps congruous to the early development of passive margin rift system under fluvial to marginal marine conditions. It is composed mainly of sandstone & shale. The Early Cretaceous period saw continued continental dominated deposition, although marginal marine conditions became increasingly common, with open marine incursions evident at the end of the rift phase. The end of rifting and onset of thermal subsidence is marked by an erosional unconformity followed by a basin wide transgression and blanketing of synrift sediments by the Raghavapuram Shale. The Raghavapuram Shale is overlain by Tirupati Formation, which was mainly deposited in a proto Godavari-Krishna delta deposition system. Tirupati Formation is overlain with flood basalts of the volcanic Razole Formation, followed by deposition of thick Tertiary sequences, basin-ward progradation with syn-sedimentary tectonic events. The generalized stratigraphy of the Krishna Godavari Basin is given in (Fig. 2).

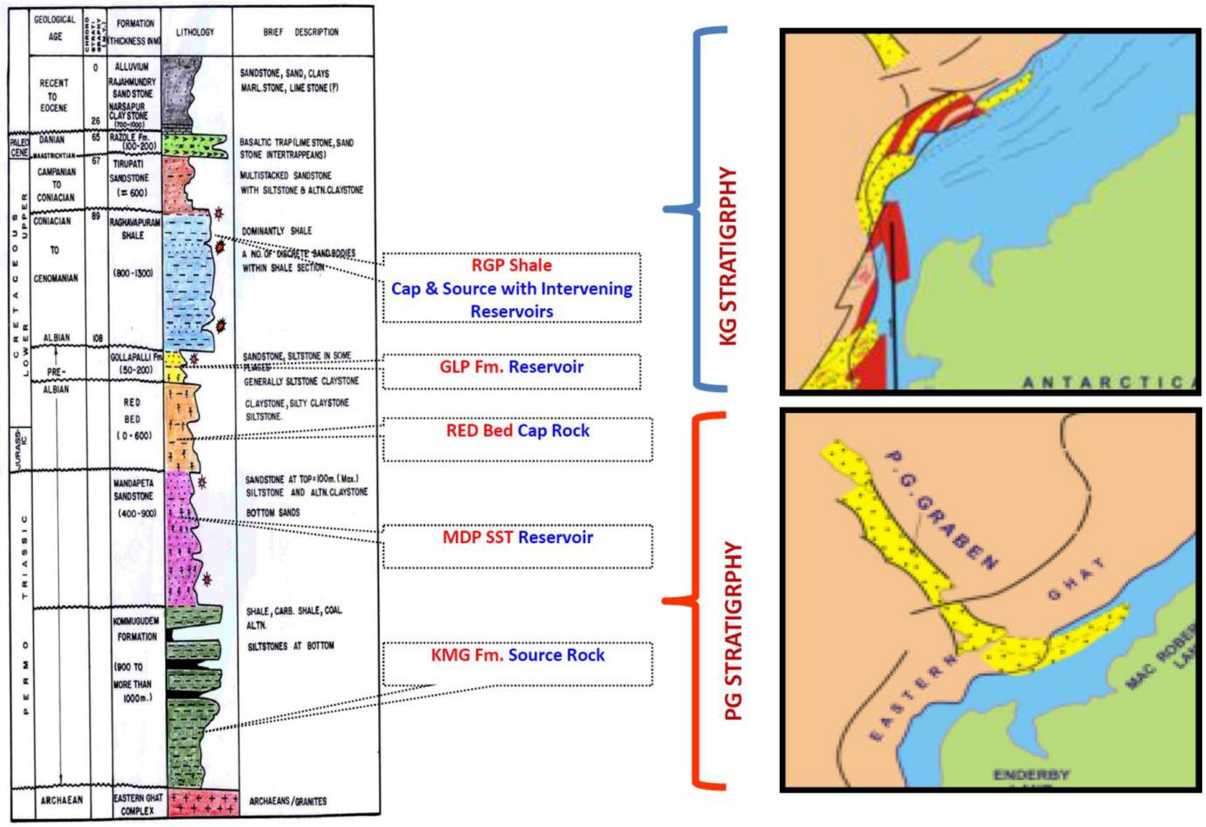

Fig.2: Stratigraphy of KG-PG basin.

Definition of Seismic attributes

RMS Amplitude

This is a post-stack attribute that calculates the square root of the sum of the squares of the amplitude divided by the number of samples in the specified window used. This root mean square amplitude can act as a direct hydrocarbon indicator in the zone of interest (SEG wiki). However, RMS is noise sensitive because it squares all the values in the window.

Instantaneous Amplitude

The instantaneous amplitude measures the reflectivity strength, which is proportional to the square root of the total energy of the seismic signal at an instant of time. The instantaneous-amplitude function of the complex seismic trace is a measure of the time variation of the total energy (kinetic plus potential) involved in the seismic reflection response (AGIWEB). This Reflectivity strength is an effective tool to identify bright and dim spots. Horizon based instantaneous amplitude was extracted and high amplitude areas are analysed.

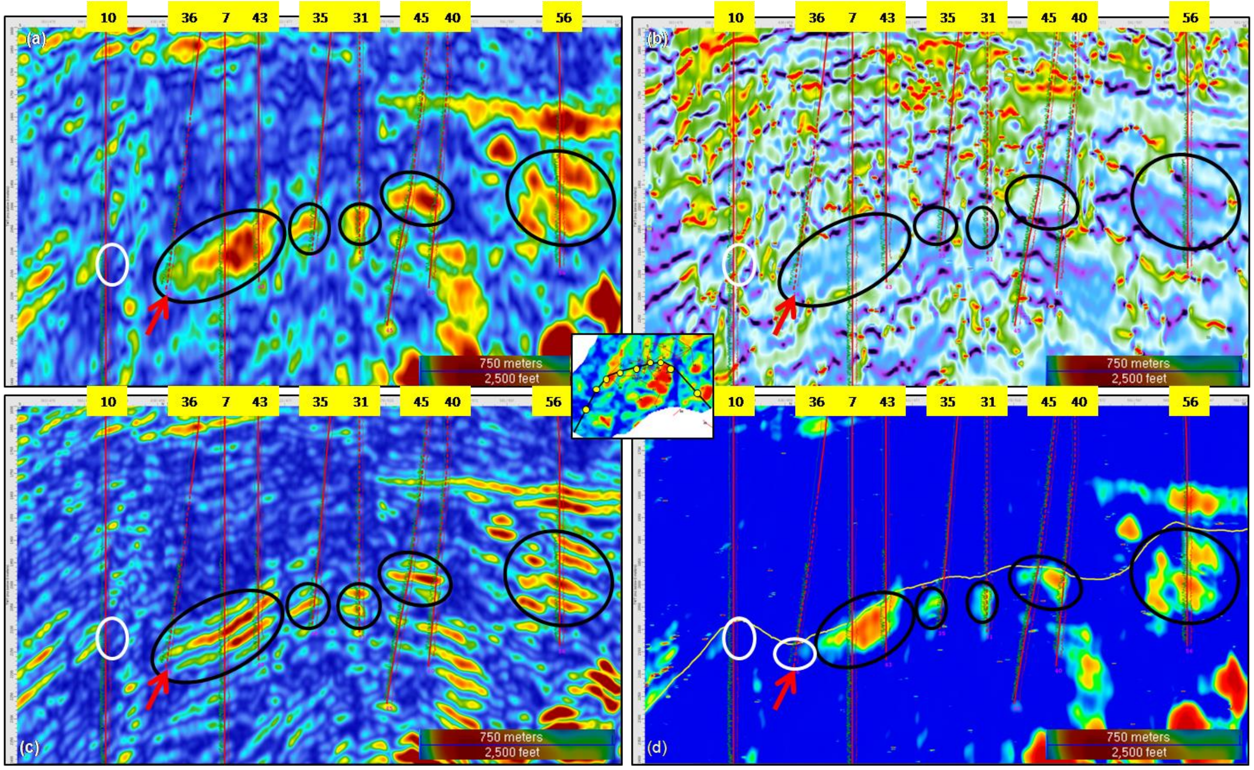

Fig.3: Arbitrary section representing (a) Reflection Strength, (b) Instantaneous frequency, (c) RMS amplitude, (d) Sweetness attributes.

Instantaneous frequency

It is the time derivative of the phase, i.e., the rate of change of the phase, and it is related to the centroid of the power spectrum of the seismic wavelet (Taner et al., 1977). The instantaneous phase is independent of trace amplitudes and relates to the propagation phase of the seismic wave front. The instantaneous phase is used to emphasize the continuity of events on a seismic section. Phase information is useful in delineating such interesting features as pinchouts, faults, onlaps, and prograding reflections. Instantaneous frequency attribute responds to wave propagation effects and depositional characteristics; hence, it is a physical attribute that can be used as an effective hydrocarbon indicator. Instantaneous frequency information can help to identify condensate reservoirs and gas reservoirs, which tend to attenuate high frequencies (SEG wiki).

Sweetness

The sweetness seismic attribute is defined by Instantaneous Amplitude (amplitude envelope) divided by the square root of instantaneous frequency as shown in equation1. This is the attribute which considers amplitude anomaly as well as frequency content of the data. Sweetness is a composite seismic attribute used to highlight thick, clean reservoirs, along with hydrocarbons contained within (SEG wiki).

$$\mathit{Sweetness} = \frac{InstantaneousAmplitude}{\sqrt{InstantaneousFrequcy}} \qquad \text{(eq.1)}$$

It can act as one of the direct hydrocarbon indicators where seismic data can capture adequate impedance contrast. It is very useful in fluvial systems for the identification of isolated sand bodies because they generate stronger and broader reflections than the surrounding shales. It becomes less useful in environments where sands and shales are highly interbedded or where contrasts in acoustic impedance between sands and shales are low (Hart, 2008). Sweetness improves the imaging of sand intervals or bodies and identifies oil and gas prone places called “sweet spots” (Radovich et al., 1998).

Seismic interpretation

Based on characters in well logs major markers are identified to be mapped in seismic. Mandapeta sandstone is divided into 6 units based on well logs, cores, cuttings, sedimentology and lab studies. These markers tied in seismic data and 4 horizons are correlated which are seismically mappable and structure maps are prepared. Among these 4 units, the top most sand is highly prolific which is extended mostly in the Northern part of the field. Horizon based attributes are extracted from this top most sand and analyzed meticulously for hydrocarbon identification.

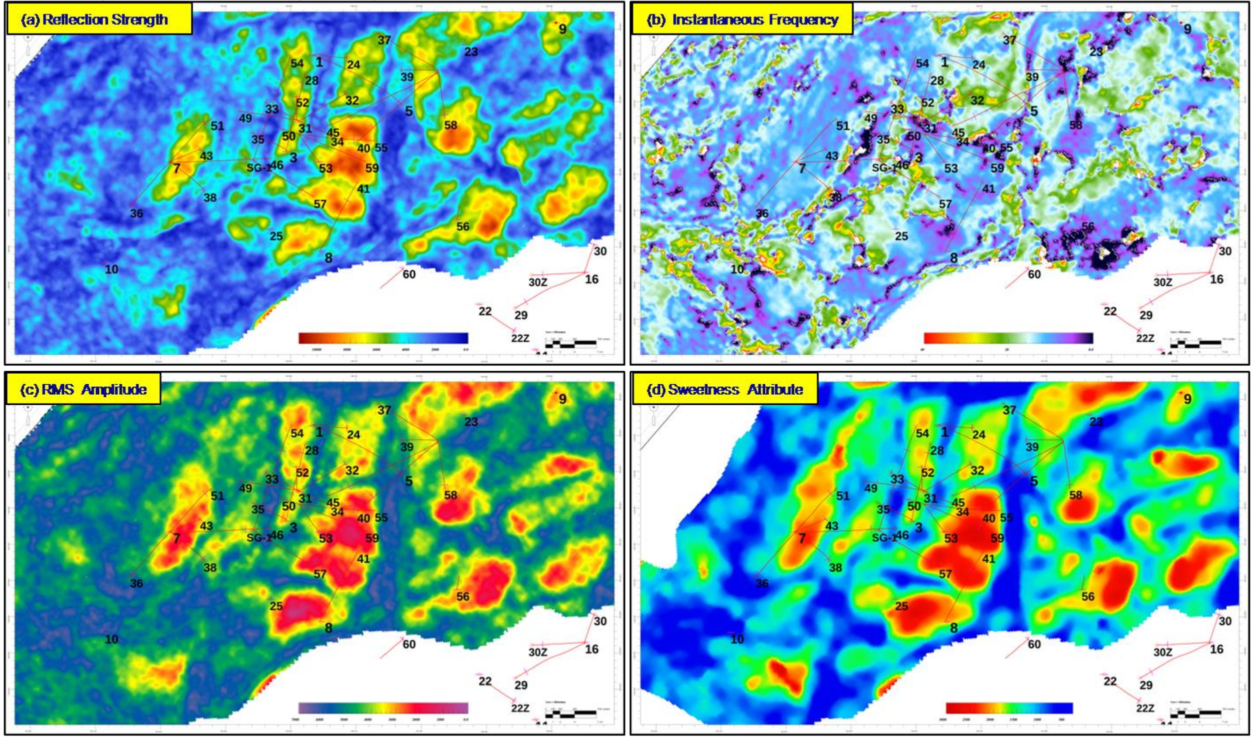
(a) Reflection Strength
(b) Instantaneous Frequency
(c) RMS Amplitude
(d) Sweetness Attribute

Fig.4: Different seismic attributes maps extracted from top most sand within 100ms window (a) Reflection Strength attribute (b) Instantaneous frequency attribute (c) RMS amplitude (d) Sweetness attribute.

Seismic attribute analysis

A wide range of seismic volume attributes such as reflection strength, instantaneous frequency, RMS amplitudes and sweetness attributes are generated in Landmark® software interface to probe the top most Mandapeta sand & structural controls potential in the study area. Fig.3 represents an arbitrary section passing through the wells 10, 36, 7, 43, 35, 31, 45, 40 & 56 to demonstrate the variation of instantaneous amplitude, instantaneous frequency, RMS amplitude and sweetness attribute in the zone of interest. High reflection strength (amplitude of the envelope) highlighted in black color ovals in Fig.3(a) analogous to major lithologic changes between adjacent rock layers; here this sharp change in amplitude represents discontinuities, which may be faults or fractures (Taner et al., 1979). This high reflection strength, i.e. bright amplitudes with respect to its surrounding indicates lateral variation in reservoir which may represent hydrocarbon bearing zones. In Fig.3(b) the highlighted zones in black ovals indicates the frequency lowering. These low frequency zones are often observed on reflections from gas sands, condensates or oil reservoirs. It can be interpreted that these low frequency zones indicates gas bearing sands. Fig.3(c) depicts RMS amplitudes and the bright amplitude areas are equivalent to that of reflection strength attribute section. Fig.3(d) shows sweetness attribute in which bright spots are demarcated in black ovals. This sweetness attribute delimits hydrocarbon bearing sands pointed in white circles in wells '10' and '36' which are devoid of high sweetness value and are dry wells. Instantaneous frequency attribute also support the same as we don't observe any frequency lowering in Fig.3(b) in well '10' marked in white oval. Reflection strength and RMS amplitude explains dry well '10' as there is no high amplitude observed in their respective attribute sections, however, these two attributes show bright amplitude in well '36' which produced water during initial testing. Hence, Sweetness attribute aided as a discriminating tool in defining the true reservoir scenarios.

Fig.4 represents various attribute maps, i.e. Reflection strength, instantaneous frequency, RMS amplitude & sweetness attribute extracted along the top most sand in 100ms window. The reflection strength and RMS amplitude attribute maps shows similar amplitude distribution throughout the area of study. Instantaneous frequency attribute map as shown in Fig.4(b) majorly demonstrates high and low frequency zones which fails to give more information to classify hydrocarbon bearing zone. Sweetness attribute which is derived from the application of both amplitude and frequency is the best candidate to utilize it for hydrocarbon identification. This sweetness attribute map shows areal extent of each of these hydrocarbon bearing zones. The wells having high sweetness value flowed gas in commercial quantities.

Conclusion

Seismic attribute analysis viz. instantaneous amplitude, instantaneous frequency, RMS amplitude and sweetness attribute helps in understanding the subsurface geology and to characterize reservoirs of a hydrocarbon province. In this study, Permo-Triassic reservoirs of Mandapeta Formation are characterized by application of seismic attribute analysis. The hydrocarbon bearing zone i.e. "sweet spots" are identified through sweetness attribute analysis which is controlled by amplitude and frequency of the seismic data. Hence, this horizon based sweetness attribute can be used as a de-risking tool for future exploration and development activities of the field.

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References

Hart, B.S., 2008, Channel detection in 3-D seismic data using sweetness: AAPG Bulletin, v. 92, no. 6, pp. 733–742

Radovich, B.J., Oliveros, R.B. 1998, 3D sequence interpretation of seismic instantaneous attributes from the Gorgon Field. Lead. Edge, 17, 1286–1293.

SEG wiki, AGIWEB (AGI learning modules)

Taner, M.T., Koehler, F., Sheriff, R.E. 1979, Complex seismic trace analysis: Geophysics, 44, 1041–1063

Taner, M.T., Sheriff, R.E. 1977, Application of Amplitude, Frequency, and Other Attributes to Stratigraphic and Hydrocarbon Determination. AAPG Memoir, Vol. 26, 301-327